ECONOMIC GEOLOGY

WITH WHICH IS INCORPORATED

THE AMERICAN GEOLOGIST

VOL. VIII AUGUST, 1913 No. 5

ON THE BEHAVIOR OF COLD ACID SULPHATE SOLUTIONS OF COPPER, SILVER, AND GOLD WITH ALKALINE EXTRACTS OF METALLIC SULPHIDES.

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INTRODUCTION.

The processes of enrichment of sulphide ores under weathering conditions offer an attractive field for experimental study. The temperatures, pressures and reagents which control the reactions of the surface zone of ore deposits are capable of laboratory duplication; and while the metals dissolved in this oxidizing acid environment are carried down to considerable depths before being precipitated in a reducing, less acid environment, it is thought that the conditions of the deeper zone also can be approximated in the laboratory. The analyses of waters from metal mines give the necessary data for the preparation of reagents. In this paper some experiments are reported regarding solvents and precipitants of the metals, and a few suggestions are made as to the reactions that are probable in the natural process of sulphide enrichment. The problem was outlined by Dr. W. H. Emmons, and work was begun in December, 1911. Throughout the investigation Dr. Emmons has very generously given most valuable suggestions and assistance.

Since the subject of the secondary enrichment was brought to

general prominence by the papers of S. F. Emmons,[1] W. H. Weed,[2] and C. R. Van Hise,[3] the importance of the process has been widely confirmed by a large amount of field work and several laboratory investigations. This has been summarized and correlated in a bulletin just issued by W. H. Emmons.[4] The secondary concentration of the metals involves their solution, transportation and deposition. The reactions that occur may conveniently be divided into two classes; first those in the higher regions, involving oxidation and solution; and second those at greater depths, involving reduction and deposition.

The experimental work that has particular bearing upon solution and reactions of the first type includes that of Vogt,[5] Buehler and Gottschalk,[6] Stokes,[7] Cooke,[8] Brokaw,[9] A. N. Winchell,[10] Grout,[11] and others. The important work bearing on the precipitation of the metals includes the experiments of Schuerman,[12] H. V. Winchell,[13] Brokaw,[14] Stokes,[15] Wells,[16] Cooke, and Palmer and Bastin.[17]

[1] Emmons, S. F., "The Secondary Enrichment of Ore Deposits," *Trans. Am. Inst. Min. Eng.*, Vol. 30, 1901, pp. 177–217.

[2] Weed, W. H., "The Enrichment of Gold and Silver Veins," *Trans. Am. Inst. Min. Eng.*, Vol. 30, 1901, pp. 424–448.

[3] Van Hise, C. R., "Some Principles Controlling the Deposition of Ores," *Trans. Am. Inst. Min. Eng.*, Vol. 30, 1901, pp. 27–177.

[4] Emmons, W. H., "The Enrichment of Sulphide Ores," Bull. U. S. Geol. Survey, No. 529, 1913.

[5] Vogt, J. H. L., "Genesis of Ore Deposits," 1896, p. 676.

[6] Buehler, H. A., and Gottschalk, V. H., "The Oxidation of Sulphides," Econ. Geol., Vol. 5, p. 28; and Vol. 7, p. 15.

[7] Stokes, H. N., "On Pyrite and Marcasite," Bull. U. S. Geol. Survey, No. 186.

[8] Cooke, H. C., "Secondary Enrichment of Silver Ores," *Jour. Geology*, Vol. 21, 1913, p. 1.

[9] Brokaw, A. D., "The Solution of Gold in the Surface Alteration of Ore Bodies," *Jour. Geology*, Vol. 18, 1910, p. 322.

[10] Winchell, A. N., "The Oxidation of Pyrite," Econ. Geol., Vol. 2, p. 290.

[11] Grout, F. F., "The Oxidation of Pyrite," Econ. Geol., Vol. 3, p. 532.

[12] Schuerman, E., "Ueber die Verwandtschaft der Schwermetalle zum Schwefel," *Liebig's Ann. der Chemie*, Vol. 249, 1888, p. 326.

[13] Winchell, H. V., "Synthesis of Chalcocite and its Genesis at Butte, Mont.," *Bull. Geol. Soc. America*, Vol. 14, 1903, p. 272.

[14] Brokaw, A. D., unpublished data given W. H. Emmons and reported in Bull. U. S. Geol. Survey, No. 529, p. 128.

A review of the work referred to above will show that several experiments resulted in the precipitation of free metals. Cooke obtained some silver sulphide, but in most of the other experiments where the sulphides were the main precipitates, the reagents are those that are rare in most mine waters, or high temperatures were used. From a careful survey of the literature it appears that chalcocite is much more abundant in enriched zones than native copper, and that secondary sulphur compounds of silver are more abundant than the free metal. It has therefore been my object to investigate conditions by which the secondary sulphides may be deposited. In some tests, with copper even after eighteen months, with varying conditions as to oxidation, using ferrous and ferric salts, and even an atmosphere of carbon dioxide, the expected sulphide precipitation has made no visible progress. In part of the tests the free metals are the only precipitates, and in others no reaction of any sort has been detected.

But if the minerals are first treated with a dilute alkaline solution and the resulting solution added to an acid sulphate solution of the metals, the sulphides are readily precipitated. Moreover, the common sulphides like pyrite, that act slowly on acid solutions, are so promptly acted on by alkalies that the solutions precipitate relatively large amounts of silver or copper sulphides from acid waters. The less common minerals niccolite and smaltite are much less active in reactions of this sort than common pyrite. In order to eliminate differences which might arise in experiments on material from different places, I have repeated, with similar results, many of the experiments referred to above. A few tests were made on several specimens of the same mineral species, and while some results varied from the average, there was, in the main, considerable uniformity.

[18] Stokes, H. N., "The Action of Solutions on Pyrite and Marcasite," ECON. GEOL., Vol. 2, 1907, p. 22.

[19] Wells, R. C., "The Fractional Precipitation of Sulphides," ECON. GEOL., Vol. 5, p. 1. Wells also reports to W. H. Emmons some data on the evolution of H_2S by the action of dilute acid on sulphide minerals; see Bull. U. S. Geol. Survey, 529, p. 59.

[20] Palmer, C., and Bastin, E. S., "Precipitants of Gold and Silver," ECON. GEOL., Vol. 8, 1913, p. 140.

Any of these experiments to be geologically significant should follow approximately the lines which nature seems to have followed. For this reason, the solutions used here have not been heated above room temperatures, and no artificial minerals have been used. Furthermore, some emphasis is to be placed on the effects of acid and iron sulphates, for nearly all mine waters from the upper zone show their presence.

It is almost impossible, without very elaborate equipment, to make such experiments with the accuracy of quantitative chemistry. There are two reasons for this; first, it may require a long time to establish an equilibrium between mineral and solution, and access of air may modify the results; and second, as will be shown below, different specimens of a mineral species, without any great variation in composition, may differ in their behavior. Qualitative and approximate results can be obtained, however, and these in the present case seem to warrant a preliminary report. Our first attempts gave negative results, especially in the work with copper, but it seems desirable to place them on record as they lead to other tests which have a bearing on the natural process.

EXPERIMENTS WITH SULPHATE SOLUTIONS.

Series I.—Stock solutions were prepared of analyzed copper sulphate, sulphuric acid and ferrous sulphate. Carefully selected specimens of pyrite, pyrrhotite, sphalerite and chalcopyrite[1] were crushed to pass a 40-mesh sieve, caught on a 200-mesh sieve, and carefully picked over by hand. In the first experiments the amounts of mineral added were enough or slightly more than enough to precipitate all the metal in the solution used, if the reaction had been carried to completeness in a simple manner as, for example,

$$ZnS + CuSO_4 = CuS + ZnSO_4.$$

[1] The pyrite was in good cubes from Central City, Colo. The sphalerite was from Franklin, N. J. The pyrrhotite was a very fine specimen from the Creighton mine, near Sudbury, Ontario. Chalcopyrite was from Gunnison County, Colo.

For the sake of comparison, the amount of each mineral used was calculated and weighed carefully to yield approximately equal surfaces to the action of the reagents.

Each of the samples weighed was treated with a liter of tenth normal copper sulphate in water. Some mixed samples were included also to determine effects of electric potential.[1] Each sample of a second set was treated with a liter of solution, tenth normal with respect to copper sulphate and twentieth normal with respect to sulphuric acid. A third set received liter portions of a solution resembling the second with the addition ferrous sulphate enough to be about tenth normal with respect to iron. These concentrations are approximately those of analyzed mine waters from regions where enrichment is supposed to be in progress.[2] Glass stoppered two-liter bottles were used as containers, and the temperatures were those of our laboratory.

After two weeks, 5 c.c. of the solution was removed from each bottle for the estimation of copper. No change could be detected. After daily agitation for ten weeks 5 c.c. more of the solution was tested, likewise with negative results. The method used to estimate the copper was delicate enough to detect a loss of $\frac{1}{20}$ of the copper of the original, while the amount of mineral added was sufficient to precipitate all the copper. It was supposed, when this lack of reaction was discovered, that the air in the bottles might explain the difficulty, as it might oxidize any hydrogen sulphide as fast as formed. To avoid this, the air was removed from the bottles by prolonged passage of CO_2, the bottles were sealed in paraffine and allowed to stand for nine months, making the total time of action a year. Still no change could be detected in the concentration of a small portion of the solution. It is my intention to test these solutions from year to year in hope of more positive results.

To test further the possible effect of oxidation in delaying the precipitation of sulphides, a similar series of samples was started with solutions freshly boiled, cooled in the absence of air, and

[1] Buehler, H. A., and Gottschalk, V. H., *loc. cit.*

[2] For such analyses see Emmons, W. H., *loc. cit.*, pp. 60–63.

poured into bottles so that the liquid and pyrrhotite—the mineral used—filled all the bottle up to a close fitting glass stopper. They have stood six months and there is no appreciable change.

In part of this series an excess of mineral sulphide was added, making the amount available sufficient to precipitate five times as much copper as was added in solution. The size of the particles, as before, was between 40 and 200 mesh. The precipitation was not apparently greater in these tests than in those with a small amount of mineral. It was discovered, however, that a very large excess of mineral, particularly if finely powdered, would precipitate copper from such solutions. It became, therefore, desirable to determine the relations between surface exposed, time of action and the amount of copper precipitated. The determination was made in a roughly quantitative way in test tubes. Five gram samples of the minerals were treated with 5 c.c. of about tenth normal copper sulphate and acid. The solution had a fairly strong color. After two to three days' treatment some of the tubes had lost most of their color, but an analysis showed that the copper was only partly precipitated. The results are tabulated below.

COPPER REMOVED FROM SOLUTION IN TWO DAYS.

5 Grams Each.	Pyrite.		Pyrrhotite.		Sphalerite.		Chlacopyrite.	
Mesh.	40–100	200–	40–100	200–	40–100	200–	40–100	200–
Grams copper added in 5 c.c. dilute acid.....	.032	.032	.032	.032	.032	.032	.032	.032
Grams copper precipitated	.005	.019	.004	.022	.001	.010	.001	.006

These results for pyrite, pyrrhotite, and sphalerite, are the averages of several values, which differ widely, only in the tests with pyrrhotite. Emmons'[1] review of the districts of the United States shows that the order of activity is probably (1) pyrrhotite, (2) sphalerite (?), (3) pyrite. It is very clear that there is a definite relation between the surface exposed and the amount of precipitation. A more detailed experiment was planned, by

[1] *Loc. cit.*, p. 93.

calculation of the approximate surface exposed in five grams of pyrrhotite of several grades of fineness, allowing a longer time of action for the coarser grades. The results are as follows:

COPPER PRECIPITATED BY FIVE GRAMS PYRRHOTITE.

Size of Grain.	20–40 Mesh.	40–100 Mesh.	100–200 Mesh.	200 Mesh.
Area exposed	73 sq. cm.	168 sq. cm.	342 sq. cm.	1000 sq. cm.
Time of action inversely as surface	30 days	12 days	6 days	2 days
Grams copper added in 5 c.c. n/10 acid	.025	.025	.025	.025
Grams copper precipitated	.003	.003	.007	.024

It is clear from this that the surface exposed is more important than the time of action. The larger surface is much more active, and in any case the action is most rapid at the beginning. To check this further the finest portion of the pyrrhotite used above was treated again for two days with some of the original copper solution, and after removing that, was treated again and again with fresh solution. The decrease in activity of the pyrrhotite is shown by the amounts removed.

ACTIVITY OF PYRRHOTITE IN EXCESS, ON SUCCESSIVE TREATMENTS WITH 0.032 GRAM COPPER IN 5 C.C. SULPHURIC ACID SOLUTION

	Copper Removed from Solution
First treatment, two days	0.031 gram —96%
Second treatment, two days following first	0.016 gram —50%
Third treatment, two days following second	0.003 gram —10%
Fourth treatment, two days following third	0.001 gram — 4%

The other common sulphides show a similar decrease in activity. If a curve is drawn, it will be seen that the action after the first month will be extremely slight. A rough calculation shows, also, that the copper precipitated in the first month is probably not enough to replace one fiftieth of the available iron in the sulphide, even with a large surface exposed. At the rate of action after the first week, it would take hundreds of years under these conditions to form a pseudomorph of a crystal a quarter of an inch thick, and it is likely that as the thickness of the altered layer increased, the action would be still slower.

Series II.—Following experiments by Wells[1] it was assumed that the acid used in series 1 was strong enough to evolve hydrogen sulphide from some of the minerals, if not from all. Since no evidence of it had been detected, it was desirable to determine how strong an acid was necessary to produce noteworthy amounts of the gas in these solutions. By repeatedly doubling the concentration of the acid it was found that a tenth normal copper solution had to be at least double normal with sulphuric acid before the Sudbury pyrrhotite liberated enough H_2S to rapidly precipitate the copper. This statement, however, if unqualified, gives a misleading impression. Other samples of pyrrhotite did not need as strong an acid as this sample from Sudbury. Some evolve H_2S from acid as weak as tenth normal. When the acid is strong enough to start the reaction in a copper solution, the copper forms a very flocculent precipitate of colloidal copper sulphide. There was no sign of an exchange of metals under these conditions, such as a replacement of iron by copper in the solid sulphide. The pyrite, sphalerite and chalcopyrite here used showed no sign of hydrogen sulphide, even when the acidity of the copper solution was 4 normal, stronger than any mine waters reported.

Two interesting points developed in these tests of pyrrhotite: first, that there is a great variation in different samples of pyrrhotite, some yielding H_2S to weaker acid than others; and, second, that the presence of a metallic sulphate in the acid solution has a retarding effect on the evolution of H_2S.

1. Samples of pyrrhotite from seven localities were available in our laboratory. The Canadian samples and one from Lancaster, Pa., were not active in precipitating copper from 4-normal acid. Samples from Vermont and New York were active in an acid of much lower concentration. Further proof of the large variation in chemical activity of a single species appears in the later series. Possibly some pyrrhotite would give H_2S with weaker acid than any in our present stock.

2. The retarding effect of sulphates in solution, on the action

[1] Wells, R. C. See Bull. U. S. Geological Survey, No. 529, p. 59.

of acid on pyrrhotite may be a matter of no special interest in theoretical chemistry, but its bearing on enrichment may be of some importance. The effect may be easily seen in a test-tube experiment. If in one tube (*A*) pyrrhotite is wet with water, and in another (*B*) with copper sulphate solution, both then being acidified to about half-normal, a lead acetate paper will be blackened much more quickly over (*A*) than over (*B*). (Temperatures have considerable effect on the rate of evolution of H_2S.) In one experiment where 10 c.c. of acid liberated much H_2S in five minutes, 10 c.c. of a solution of the same acidity with one milligram of copper (one part in 10,000) did not blacken the paper for thirty minutes. It might be supposed that the HS liberated in tube (*B*) failed to blacken the test paper because it was used up in reacting with the copper present; but after the evolution of H_2S had proceeded for several minutes in tube (*A*), the amount evolved was found by test to be more than sufficient to precipitate as much copper as was added to tube (*B*). The copper in tube (*B*), however, had not been precipitated. It is evident that the acid does not react upon the pyrrhotite of tube (*B*) to produce much H_2S. In another test a small amount of copper solution retarded the evolution, not only thirty minutes, but apparently permanently. Other sulphates have a similar, but much less notable, retarding effect. On the other hand, it is possible that some other substance might have an accelerating effect; and it is probable that some ground waters contain sulphuric acid enough to produce H_2S, without containing enough copper to retard the action.

Series III.—Since the minerals and solutions of the first experiments did not give as active a sulphide precipitation as was expected, a larger series of both minerals and solutions was prepared. The conditions and results are comparable with those of Palmer and Bastin,[1] but in order to approximate more closely to conditions indicated by analyses of waters from the upper zones of metal mines, the solutions in my experiments were made acid with sulphuric acid (about tenth normal), and in a later test

[1] *Loc. cit.*

(series IV.), iron sulphates were introduced. I have added some experiments with copper sulphate. The list of minerals selected also varies slightly from those used in the work of Palmer and Bastin, and most of the specimens were from different localities. They were carefully selected, but not analyzed. As may be seen from the parallel columns of Table I., the resulting order of activity is about the same. I have tried to arrange my results in four groups to correspond to Palmer and Bastin's: (1) weak, (2) moderate, (3) strong, (4) very strong.

(*a*) In the tests with silver, agreement is noteworthy in view of the fact that my solutions differed greatly in acidity, and that the activity of a single mineral species differs greatly in some experiments, as will be shown below.

It is of interest to determine the reaction causing this precipitation. Only metallic silver was seen in watching the precipitation in a test tube, but by using powdered chalcocite and an excess of silver solution till no further action occurs, one can obtain a residue and solution such as Palmer and Bastin have reported.

$$Cu_2S + 2Ag_2SO_4 = 2CuSO_4 + Ag_2S + 2Ag.$$

This is very surprising, as silver is precipitated in two forms by a single reaction. By using some lumps about ⅛ inch in diameter and allowing only three hours for the action, it is possible to remove the spongy silver precipitates from the chalcocite, mechanically, without washing off any sulphide or leaving very much metallic silver. In this experiment the silver removed in metallic form was .370 gram, while that remaining attached or combined as sulphide was .095 gram. The first reaction that takes place is probably

$$Cu_2S + Ag_2SO_4 = CuS + CuSO_4 + Ag_2.$$

If this occurs the cupric sulphide reacts later to yield silver sulphide.

Metallic silver is sometimes referred to as a secondary product from the oxidation of argentite, and it was thought possible that

argentite might be formed here momentarily, and at once transformed to silver by the oxidation of sulphur. By boiling the solu-

TABLE I.

ORDER OF ACTIVITY OF MINERALS IN REDUCING ACID FERRIC SULPHATE, COMPARED WITH THEIR ACTIVITY ON SOLUTIONS OF GOLD, SILVER, AND COPPER.

	Order of Reducing Action on Ferric Sulphate.	Activity in Precipitating Silver.		Activity in Precipitating Gold.		Activity in Precipitating Copper Estimated from Visible Action in Two Months.
		1[a]	2	1[a]	2	
Alabandite ..	200.[b]	Strong	Very strong[c]	Very strong	Very strong	Very strong[c]
Niccolite....	18.	Very strong	Very strong	Very strong	Very strong	None.
Tetrahedrite.	15.	.....	Strong	.....	Very strong	None.
Covellite....	?	Strong	.....	Very strong	.....	None?
(Siderite)....	15.	.....	Weak	.....	Very strong	None.
Cobaltite....	?	Strong	.....	Strong	.....	None?
Smaltite.....	13.5	Moderate	Very strong	Strong	Very strong	None.
Pyrrhotite...	13.2	Moderate	Strong	Strong	Very strong	None.
Arsenopyrite.	12.5	Moderate	Strong	Strong	Very strong	None.
(Cuprite)....	10.5	.....	Strong		Strong	None.
Molybdenite.	9.5	.....	Weak		Very strong	None.
Millerite....	9.3	Weak	Weak	Moderate	Strong	None.
Galena.....	7.3	Weak	Weak	Very strong	Very strong	None.
Chalcocite...	5.1	Very strong	Strong	Very strong	Strong	None.
Bornite.....	4.7	Strong	Strong	Very strong	Very strong	None.
Jamesonite...	?	Weak	.....	.....	.....	None?
Enargite....	4.6	Strong	Moderate	Very strong	Moderate	None.
Marcasite...	4.5	Moderate	Weak	Very strong	Very strong	None.
Tennantite...	4.4	Strong	Very strong	Strong	Very strong	None.
Black Jack...	4.0	.....	Weak	.....	Very strong	None.
Stannite.....	4.0	.....	Strong	.....	Strong	None.
Orpiment....	3.7	Weak	Weak	.....	Very strong	None.
Pyrite.....	3.1	Weak	Weak	Moderate	Very strong	None.
Rosin Jack...	3.0	Weak	Weak	Weak	Weak	None.
Cinnabar....	2.5	Weak	Weak	Weak	Strong	None.
Stibnite.....	2.3	Weak	Weak	Moderate	Very strong	None.
Chalcopyrite.	2.3	Moderate	Weak	Moderate	Very strong	None.
Realgar.....	1.0	Weak	Moderate	.....	Very strong	None.
(Ferrous silicates, etc.)	1.0	.....	Weak	.....	Weak	None.

[a] Columns numbered 1 were estimated, in water solutions of the salts of the metals, by Palmer and Bastin (ECONOMIC GEOLOGY, Vol. 8, p. 140). The rest of the work was done in dilute sulphuric acid solutions.

[b] Figures indicate the c.c. of permanganate used in titrating the reduced solution.

[c] Alabandite, in acid solutions of silver and copper, gave sulphide precipitates. All other visible precipitates were the free metals.

tion and cooling rapidly in CO_2, the oxidation by air can be avoided. This was tried, but metallic silver was abundant in the precipitate obtained.

(*b*). The same series of minerals was tested with gold solutions, somewhat more dilute than those used by Palmer and Bastin and acidified as before with H_2SO_4. With this solution no such spongy gold as they described was produced. The minerals were plated until the gold was removed from solution. Here also the results are tabulated in parallel columns in Table I. The agreement in tests with gold is less noteworthy, probably because gold is precipitated almost completely by a great many minerals. Attention is called to the fact that black jack is much more active than rosin jack, especially in its action on gold chloride. This variation in activity with slight change in composition suggests that similar variation in the composition of other minerals may explain the lack of complete agreement in the rest of the table.

It is noteworthy that in these tests the cuprous minerals, cuprite, chalcocite, enargite, and stannite become plated with gold very promptly, but the action is not complete, even after standing several months. These minerals, moreover, are the only minerals more active in removing silver than in removing gold from the solutions.

The action of oxides, carbonates and certain silicates on metallic sulphate solutions is of different order from the chief results here reported. Tests of kaolin and orthoclase have been made by Sullivan.[1] The fact that the metals were removed from solution in small quantities indicates that such silicates should be included in a table like the one here given, if an attempt was made to make it complete. They would probably constitute a group showing "very weak" action. The action of carbonates is worthy of note from the fact that the acid of the solution had to be nearly neutralized in forming sulphates before there was much precipitation of the metals.

These tests may have some significance in the study of nature's

[1] Sullivan, E. C., "Interaction of Minerals and Water Solutions," Bull. U. S. Geol. Survey, No. 312.

process of depositing native metals, but to me there is also a negative significance of great importance. Many secondary ores consist of sulphides without native metals, and the method of their formation is evidently not duplicated by these laboratory tests. It has been stated that pyrite and chalcocite react on silver solutions to yield argentite,[1] but these experiments yield the free metal whenever any precipitation occurs. Nature's conditions must be different from these.

(*c*) In the series of tests made with copper solutions, alabandite was the only mineral which had a noteworthy precipitating effect, and this in acid solution evolved H_2S which bubbled up through the solution forming colloidal copper sulphide. One or two grains of metallic copper also appeared after most of the acid was neutralized. In this connection, it may be of some interest to report a simple experiment showing that metallic copper reacts with freshly precipitated sulphur in much the same way that silver reacts with sulphur.[2] Though no precipitates were visible in many tests with copper solutions, the tests of series I show that there was probably some reaction.

Series IV.—It is known that ferrous sulphate will precipitate gold and silver from dilute acid solutions, as well as the minerals used in series III. It was thought that the activity of the minerals in reducing ferric iron to the ferrous state might possibly be an index to their activity in reducing sulphates of the more valuable metals, under ordinary conditions. Ferrous salts themselves have not been found to reduce sulphates to sulphides at ordinary temperatures, but it seemed probable that if some natural reagent were found to reduce sulphates to sulphides, the presence of excess of ferric sulphate would prevent the reaction, while ferrous sulphate would not. For example, if one places in two test tubes alabandite—the most active sulphide in acid solution—and adds to the first tube acid copper sulphate, and to the second ferric sulphate and acid copper sulphate, it is evident at

[1] Clarke, F. W., "The Data of Geochemistry," Bull. U. S. Geol. Survey, No. 491, p. 620; Van Hise, C. R., "A Treatise on Metamorphism," Mon. U. S. Geol. Survey, No. 47, p. 1168.

[2] Cooke, H. C., *loc. cit.*

once that the ferric sulphate delays and reduces the activity of the formation of copper sulphide. Since most waters in the upper zone of ore deposits probably carry iron sulphate, the state of oxidation of iron may be a controlling factor in the precipitation.

Preliminary to the principal determinations of this series, several minerals were treated with the following solutions: (1) Silver sulphate, (2) silver and ferrous sulphates, and (3) silver and ferric sulphates. Silver was precipitated almost at once by ferrous sulphate whether any active mineral was present or not, but a sulphide mineral made the action more nearly complete. Enargite (from Butte) is a good mineral to show the contrast in the action in different solutions, for while all the silver is removed from a simple silver sulphate solution in a week, mostly as metallic silver, no metallic silver whatever is precipitated from a mixed solution of silver and ferric sulphates. It is clear that the type of reaction reported in series III is for some minerals wholly dependent on the absence of much ferric sulphate. Active minerals like chalcocite, however, reduce ferric sulphate so promptly that metallic silver develops very readily, while the less active minerals like pyrite act so slowly that it is difficult to discover any precipitation whether ferric iron is present or not. Pyrrhotite, chalcopyrite and black jack act much like enargite. Furthermore, a mixture of equal parts of ferrous and ferric sulphates will act like ferric sulphate alone in this reaction so that a mineral water will have to be thoroughly reduced before free silver will precipitate. The few analyses of mine waters available show a wide variation in this respect.

Although ferric sulphate prevented the formation of metallic silver and there was no visible sign of any reaction in some of the experiments described above, the pyrrhotite, enargite, stannite and some others do remove silver from solution even in the presence of ferric sulphate, probably as a sulphide. There is thus indication that ferric sulphate under some conditions determines not only the precipitation of silver, but also whether the precipitate consists of the free metal or the sulphide. In the absence of ferric sulphate, metallic silver is most prominent; in its presence,

the silver is more likely to be precipitated as sulphide by an exchange of metals in the mineral. The recent work of Cooke[1] apparently supports this conclusion. He found that 200 c.c. of acid ferric sulphate dissolved not over 0.0074 gram of silver sulphide in 98 days; while 75 c.c. of a similar solution dissolved 0.0825 gram of metallic silver in 73 days. If larger amounts act in proportion, silver is over twenty times as soluble as argentite. Argentite the less soluble mineral, may thus form in a solution containing so much ferric sulphate that no metallic silver can be formed. Gold and copper, however, do not seem to have the same intimate relation to ferric sulphate. Gold is so easily reduced to metallic form that the sulphide is unknown in natural deposits; while copper is reduced to the metallic form less easily than silver, and its sulphide is common.

The relative rates at which several minerals reduce ferric sulphate were roughly determined. Three grams of each mineral, powdered between 20 and 200 mesh, were treated with 10 c.c. of a ferric solution in test tubes. The tubes were corked (but without special care) and allowed to stand with occasional agitation for two days. The solutions were then diluted and titrated with permanganate solution (1 c.c. = 1 milligram of iron). The table shows the number of c.c. required to give a pink color. The minerals above galena in the list not only reduced all the iron added, but contributed some further reducing agent, such as ferrous sulphate from the pyrrhotite, or H_2S from the alabandite. The results were slightly higher in tenth normal acid than in a nearly neutral solution, but the order of activity was similar. It is apparent from a glance at the table that the order of activity in reducing ferric solutions is not identical with that in precipitating gold or silver from solution. Neither is it the same as the order of activity in yielding H_2S in acid solution. It cannot be depended on, therefore, as a reliable indication as to which minerals are favorable to the precipitation of the sulphides of the valuable metals. However the state of oxidation of iron in ground waters is the most available index to the nature of the reactions expected, and I have arranged Table I. on this basis.

[1] *Loc. cit.*, pp. 13 and 14.

A similar table might be constructed, using as an indicator, instead of permanganate, a test that shows the length of time required for the mineral to reduce enough ferric salt so that the ferrous sulphate in solution will precipitate silver or gold. Possibly with such an indicator the order would be somewhat changed, but so far as indicated by tests on several of the minerals, the changes would be slight.

Some minor observations may be mentioned:

1. In this test again, the variation in a single species is prominent—so prominent, in fact, that with other specimens, the position of a mineral like pyrrhotite in the table would be considerably changed. The seven samples of pyrrhotite mentioned in the tests for H_2S were tested with ferric sulphate, and while six samples resulted in a reduction of from 2 to 4 c.c. of permanganate, the seventh required 32 c.c. This most actively reducing pyrrhotite is not the specimen evolving the most H_2S. Such variations in pyrrhotite may be due to impurities, or to its well-known variable nature. Other minerals are more constant in their relation to ore deposition.

2. The action of ferric sulphate on pyrite and marcasite has been noted by Stokes.[1] The results here stated, however, may be a more definite indication of the natural process of oxidation of pyrite, because the action was measured at a temperature and a concentration of solution resembling those of ordinary mine waters. The solution contained about two grams of ferric sulphate per liter. The surface exposed to the action of the solution was roughly calculated as about 60 square centimeters for the amount added. If ground water circulation kept a solution of this quality in contact with a surface of 60 square contimeters of pyrite, a liter of solution would oxidize 8 grams of pyrite per year. This is a much more rapid oxidation than is found with water alone, and since the salts used are those produced by the reaction, it may have some significance in accounting for the rapidity of the natural process. To make certain that the solution reaction was not retarded, as was found to be the case in

[1] Stokes, H. N., *loc. cit.*

precipitation reactions, a sample was treated repeatedly with fresh portions of ferric sulphate. Titrations on successive days were as follows: 3.3, 2.8, 2.7, 2.7, 2.9, 3.0, 3.1. Such differences as appear are probably due to a variation in room temperatures, or the thoroughness of agitation and contact of solution and mineral. The reaction is assumed to be

$$7Fe_2(SO_4)_3 + FeS_2 + 8H_2O = 15FeSO_4 + 8H_2SO_4.$$

If, as Stokes suggests,[1] the reaction occurs in two parts, yielding some separated sulphur, the amount of pyrite attacked was even greater. The table shows that marcasite and pyrrhotite are more rapidly attacked than pyrite. Chalcopyrite, on the other hand, is less attacked, but there is a notable reaction even here. The attack upon sphalerite varies greatly, apparently depending upon the iron content. It is usually more rapidly affected than pyrite. It would appear from this that ferric sulphate in acid solution is probably one of the most important oxidizing agents concerned in the enrichment of ores.

3. It is interesting to find, also, that the rate of oxidation of minerals by ferric sulphate agrees fairly well with the order of oxidation observed in field studies of sulphide ores. These observations have recently been tabulated, with some results of other laboratory work by Emmons.[2] Also it is noteworthy that the order given, and the order of activity in precipitating gold and silver and copper, are not the same as might be expected from a study of Schuerman's series,[3] the chief exceptions being due to the low activity of the di-sulphides like pyrite, and the high activity of cuprous compounds.

Summary of Work with Acid Solutions.

When this series of experiments was begun it was intended to illustrate as nearly as possible the precipitation of metals in the secondary sulphide zone. Conditions were varied to include in

[1] *Loc. cit.*
[2] *Loc. cit.*, p. 76.
[3] *Loc. cit.*

several series, solutions that were neutral, solutions that were acid, solutions that contained acid ferric sulphate, and solutions that contained acid ferrous sulphate and were strongly reduced and kept out of contact with air. But whenever much precipitation occurred, the free metals were prominent. Except on alabandite, copper was not notably precipitated as sulphide, although several sulphides were in contact with solutions for eighteen months; and silver was in nearly every case precipitated as free metal unless ferric sulphate was present. In sulphide ores, however, chalcocite is the principal secondary mineral and metallic silver, though abundant in some deposits, is very sparingly present in many important districts as, for example, at Tonapah and in the Comstock Lode, Nevada. These unexpected results have lead to a conviction that the conditions of these experiments are not identical with those that obtain where secondary sulphides are precipitated.

With conditions resembling those in the earth, it is known that sulphides may be formed in at least three ways: (1) by a liberation of H_2S, as from pyrrhotite or alabandite; (2) by an exchange of metals in a mineral, as copper or silver replaces iron in pyrrhotite; and (3) by the action of alkaline sulphide solutions. The last of these remained to be tested, and series V. is the result. Some references in the literature have significance in this connection.

Review of Work on Alkaline Solutions of Sulphides.

In discussing the source of the sulphur in secondary sulphides W. H. Emmons says:[1]

"Where . . . sulphides are replaced pseudomorphously by secondary sulphides the sulphur has evidently remained in place. . . . Some of the secondary sulphide ore is found in cracks that cut the older sulphides. In some of these cracks the secondary minerals have replaced an older veinlet of primary ore, but in others the ore has clearly been deposited in an open space. . . . These relations . . . strongly suggest hydrogen sulphide or alkaline sulphides as agents precipitating some secondary sulphides."

[1] *Loc. cit.*, pp. 87–88.

Clarke says:[1]

"A water containing alkaline carbonates and free carbonic acid should decompose the sulphides at great depth. . . . Alkaline sulphides would thus be formed in which the sulphides of the heavy metals are variably soluble. In such solutions the sulphides of tin, arsenic, and antimony dissolve freely and other sulphides in smaller amounts."

Precipitation from such solutions may result from reaction, change of temperature, or even from dilution. Becker[2] reports some details not covered in this general statement. Cinnabar, pyrite, marcasite, and sulphides of zinc, copper, arsenic, and antimony are soluble in alkaline solutions even in the cold. Lead and silver sulphides are much less soluble. This work in cold solutions is especially noteworthy, as most of the experiments in alkaline solutions have been conducted at high temperatures.[3]

Ransome,[4] in a study of the Goldfield deposits, suggests that the "ore constituents were brought up in hot solution charged with hydrogen sulphide, a little carbon dioxide, and probably also with some alkali sulphides; that the hydrogen sulphide was oxidized at and near the surface to sulphuric acid, which percolated down through the warm rocks to mingle with the uprising currents; and that the precipitation of the richest ores took place in the zone where the two kinds of solutions mingled and as a consequence of such mingling."

While the statements often made concerning precipitation by mingling of solutions are intended to apply to the deposition of primary ores, a hypothesis of mingling solutions, it appears to me, might be considered in connection with precipitation of secondary minerals at lower temperatures. Alkaline mine waters are not rare below the zone of oxidation. Of the thirty-seven available

[1] Clarke, F. W., "The Data of Geochemistry," Bull. U. S. Geol. Survey, No. 491, pp. 603 and 609.

[2] Becker, C. F., "Geology of the Quicksilver Deposits," Mon. U. S. Geol. Survey, No. 13, pp. 419–439.

[3] DeClermont and Frommel, *Annales Chim. Phys.*, Vol. 18, p. 189; Doelter, C., *Min. pet. Mitt.*, Vol. 11, p. 390.

[4] Ransome, F. L., "Ore Deposits of Goldfield, Nevada," Prof. Paper U. S. Geol. Survey, No. 66, p. 193.

analyses of mine waters, as least eight are alkaline and some of these were collected within 400 feet of the surface.[1] Deep waters of acid reaction are not recorded. Even in an open shaft the deeper waters are less acid than those at the surface. The change in acidity results partly from reactions with the wall rock, but any ascending waters may contribute some alkali. Such deeper waters may, of course, have obtained their alkali by long contact with the wall rock. With alkaline solutions reactions like those stated below might take place.

1. $$Na_2S + CuSO_4 = CuS + Na_2SO_4.$$

2. $$(Na_2S)x \cdot Sb_2S_3 + xH_2SO_4 = Sb_2S_3 + xNa_2SO_4 + xH_2S.$$

3. $$\begin{pmatrix} 5Na_2S \cdot Sb_2S_3 \\ \text{alkaline solution} \end{pmatrix} + \begin{pmatrix} 5Ag_2SO_4 + H_2SO_4 \\ \text{acid solution} \end{pmatrix} = \begin{pmatrix} 5Na_2SO_4 + H_2SO_4 \\ \text{acid solution} \end{pmatrix} + \begin{pmatrix} (Ag_2S)_5 \cdot Sb_2S_3 \\ \text{Stephanite} \end{pmatrix}.$$

Reaction (1) shows the precipitation of copper from an acid solution by addition of a soluble sulphide. Reaction (2), on the contrary, shows the precipitation of a metallic sulphide by the acidification of an alkaline sulphide solution of the metal. Reaction (3) shows the formation of a double salt which results when both the acid and alkaline solutions contain ore metals. The acidification of an alkaline sulphide solution by sulphuric acid should precipitate sulphides of any heavy metal that may be present in either solution. If both the acid and alkaline solutions contained the same metal, a very rich sulphide might form; if different metals, double salts are to be expected. Laboratory work was planned to determine, first, whether or not the sulphide minerals are easily attacked at ordinary temperatures by dilute alkaline waters, and the relative rate of attack for different minerals; and, second, whether or not the sulphides and double sulphides are precipitated when an acid solution containing metallic sulphates is added.

[1] Emmons, W. H., *loc. cit.*, pp. 60–71.

Experiments with Alkaline Solutions.

Series V.—Using 1 per cent. sodium bicarbonate on an excess of the sulphide minerals, the series of Table II. was roughly estimated. The tests were made in corked test tubes, but without any special precaution to avoid oxidation, using 10 c.c. of solution on three or four grams of the minerals powdered between 40 and 200 mesh. After two days the action was so great that the relative activity of different sulphides could be determined by taking out of the tube about 1 c.c. of the extract. The presence of sulphide in the solution was detected by adding silver sulphate and a slight excess of sulphuric acid. Silver sulphide usually formed as a black colloidal precipitate. No H_2S was evolved with the CO_2 during acidification, even when a large bulk of solu-

TABLE II.

Estimated Order of Activity of Alkaline (1 per cent.) Solutions, in Attack on Sulphide Minerals, Tested by Addition of Silver Sulphate and Sulphuric Acid.

	$NaHCO_3$ 1 Week at 25° C.	Same Continued 1 Week at 50° C.	Na_2CO_3 1 Week at 25° C.	Same Continued 1 Week at 50° C.	K_2CO_3 1 Week at 25° C.	NaOH 1 Week at 25° C.
Orpiment	100[1]	100	100	100	100	100
Stibnite	35	35	20	20	20	100
Pyrrhotite	20	25	18	20	8	10
Realgar	12	22	25	20		
Marcasite	8	13	2	8		4
Alabandite	6	14	2	10		8
Pyrite	5	7	5	9	15	10
Millerite	4	8				
Galena	4	9	2	8	11	10?
Black Jack	3	4	4	10	11	4
Chalcopyrite	2	3	2	8	10	
Stannite	2	2				
(Coal)	2?	3?				
Tetrahedrite	2	1				
Smaltite	2	2	3	10+	6	
Arsenopyrite	1	0?				
Cinnabar	1	2				
Enargite	1	1				
Chalcocite	0	0	0	0		
Bornite	0	0				
Rosin Jack	0	1	0	0		
Niccolite	0	0				

[1] Figures are relative only, and were estimated from the volume of precipitates.

tion was tested. If any formed it was used up at once in precipitating metallic sulphides. The precipitates obtained by similar testing after a week were somewhat more bulky than those in two days. The tubes were then warmed to about 50° C. for five days, when a still further concentration of sulphides was found in solution. The results stated in Table II. are relative, rather than quantitative.

Sodium carbonate was used instead of the bicarbonate on a second series of experiments and gave similar results. In a third series the minerals were tested with dilute sodium hydroxide with subsequent addition of acid silver sulphate. In a fourth series, which gave similar results to those of the third, diluted sodium silicate was substituted for sodium hydroxide. It is well known that sodium silicate reacts much as sodium hydroxide, the silica being colloidal. In a fifth series potassium carbonate was used as the alkaline reagent. These different groups of tests were not made as complete as the first in which the alkaline solution was the common sodium bicarbonate, but the minerals tested show that the action is of the same general nature in each solution. The data are given in Table II. It is noteworthy that after a mineral has been tested with a dilute alkaline solution for a week or more, it is not changed in any way to interfere with further action of alkalies. If the solution is removed and the mineral treated with a fresh solution, the solvent action is as great as in the first treatment.

The rate at which alkali dissolves the sulphides is most readily determined by silver sulphate. Gold, copper and zinc may be used, but are less satisfactory. Lead cannot be used in sulphate solution because the sulphate is so slightly soluble. The use of gold solution resulted first in the formation of gold sulphide, but some metallic gold deposited on the sides of the tube after standing. Zinc sulphate solution yielded zinc sulphide when treated with the alkaline extract of sulphides, but an excess of acid promptly dissolved the precipitate. The use of copper sulphate under some conditions resulted in the formation of copper sulphide, but the reaction was not as clear and satisfactory as in the

experiments with silver. Only when a large amount of the sulphide was present in the alkaline extract was copper precipitated promptly. Though the copper and sulphide radicles were both present, there was evidently something else present in some tests, to prevent the precipitation. Possibly the carbonic acid, liberated from the alkali carbonate in acidification, is sufficient to keep the sulphide in solution. This is indicated by the fact that after standing, CO_2 is evolved and the copper sulphide does precipitate. Slight warming greatly facilitates the evolution of CO_2 and precipitation of copper.

The formation of double sulphides, or sulpho-salts by this process is noteworthy and was tested in a little more detail. Portions of silver sulphate were added to 10 c.c. of the 1 per cent. sodium carbonate extract of stibnite, and the composition was tested for varying amounts of silver added.

ANALYSES OF THE PRECIPITATES OBTAINED FROM VARIOUS MIXTURES OF ACID SILVER SULPHATE AND ALKALINE ANTIMONY SULPHIDE SOLUTIONS.

Mixture used.....	Grams silver sulphate	.0000	.0083	.0415	.0830	.1660
	Grams antimony sulphide.....	.0050	.0050	.0050	.0050	.0050
Precipitate obtained...	Grams Ag_2S.....	.0000	.0066	.0095	.0097	.0100
	Grams Sb_2S_3.....	.0048	.0032	.0025	.0024	.0024

From small amounts of the silver solution all of the silver was precipitated, but when larger amounts were used, both metals were partly precipitated, and partly remained in solution. It was found, further, that when no silver was added, a little antimony remained in solution, the remainder forming an orange colored sulphide. The work of Doelter[1] would indicate that the sulphides dissolve without decomposition; but if so, possibly some sulphur was oxidized after solution, thus leaving the antimony in excess. Whenever silver was present, both metals precipitated. This was true even when the silver present was many times as much as was precipitated. When there is enough or more than enough silver present to unite with the antimony, the analyses

[1] *Min. pet. Mitt.*, 11, 1890, p. 319.

above indicate approximately the composition of stephanite $(Ag_2S)_5 \cdot Sb_2S_3$.

Wells work[1] would indicate that the double sulphides are not formed by H_2S in a simple reaction, and Cooke in his work on silver concludes[2] that sulpho-salts are not likely to form by the action of acid silver solutions on the sulphides of antimony and arsenic. These results would indicate that the double salts are not formed by simple action of acid solutions, but it is possible to form them when acid solutions are mixed with alkaline solutions. In testing an alkaline solution of the iron sulphide with acid copper sulphate, warm, both copper and iron are precipitated. In some tests much copper and only a trace of iron were precipitated, while in others the iron was nearly equal to the copper. A quantitative study is now being conducted to determine the conditions required for the formation of the double sulphide.

The possibility is suggested, further, that if an alkaline sulphide solution of two metals, without much excess of carbonate, was only partly acidified, double salts of different composition might be formed.

Certain relationships in Table II. are especialy significant. The sulphides of antimony and arsenic, which are easily attacked, are prominent in enriched ores as sulpho-salts of the metals. Ransome says:[3]

> "Argentite, proustite, pyrargyrite, stephanite, polybasite, and probably a goodly number of the more complex sulpharsenites and sulphantimonites may prove to be as characteristic of downward enrichment as chalcocite."

Second only to orpiment and stibnite come to the sulphides of iron, and then the lead and nickel minerals. All these seem to yield solutions capable of precipitating sulphides very copiously, compared with the activity of minerals directly upon dilute acid solutions. Of third rank is the mineral alabandite. Manganese

[1] Wells, R. C., "Fractional Precipitation of Sulphides," ECON. GEOL., Vol. V., p. 1.

[2] Cooke, H. C., *loc. cit.*

[3] Ransome, F. L., "Criteria of Downward Sulphide Enrichment," ECON. GEOL., Vol. V., p. 211.

sulphide readily precipitates other metals from acid solutions by evolving H_2S, but it is comparatively rare in ore deposits—at least in the deposits of North America—and in the processes of sulphide enrichment it has apparently played a subordinate rôle. Under alkaline conditions it is noteworthy that the more abundant iron sulphides are fully as active as this less common alabandite.

A comparison of the activity of acid vs. alkaline reagents is not possible from the tables given—the data being relative in each case—but quantitative data can be reported for some minerals. Cooke treated stibnite (40–80 mesh) with silver solution for 36 days, after which he found the mineral contained 1.3 per cent. silver. This would indicate at least five years as the time needed to convert powdered stibnite to such a mineral as stephanite (68 per cent. silver). I have treated such a powder with 100 c.c. of 1 per cent. alkali solution for a week, and weighed both the residue and the silver which could be precipitated by the extract. About 5 per cent. of the stibnite dissolved and reacted to form a precipitate suggesting stephanite. The residue of stibnite was treated another week with fresh alkali, and again lost 5 per cent. of its original weight, showing that the process does not develop compounds which retard further action. At this rate such stibnite would be completely dissolved by alkalies within six months, one tenth the time needed for complete reaction with acid solutions. Pyrrhotite, on the other hand, removed more silver from acid solution (mostly in metallic form) than was precipitated by an alkali extract of similar pyrrhotite. This corresponds to the results in Tables I. and II. Stibnite is much more active in alkaline than in acid solutions, while pyrrhotite is active in both solutions. This is to be interpreted as an indication that enrichment by stibnite yielding sulpho-salts is more likely to occur if brought about by the action of mingling acid and alkaline solutions, than if acid solutions act directly on the minerals; while pyrrhotite may produce a small and greatly enriched zone, either by direct action on acid solutions, or by mingling of acid and alkaline solutions. Attention is called to the fact that, though

the order of attack by alkalies is not the same as the order of attack by acids, neither is it exactly the reverse. Some minerals are active in both acid and alkali; some are little affected in either; and some are very active in one but much less in the other. The position of the common sulphide, pyrite, is of special interest because it appears to react very readily with alkaline solutions, while acid solutions of metals attack it very slowly.

SUMMARY.

In the pages above are stated several series of experiments designed to indicate the natural process by which secondary sulphides of the metals may be precipitated. Gold is removed from its acid solutions by several minerals, but largely in the metallic form. Metallic silver also results from the action of several minerals on acid solutions, especially if free from ferric salts. In nature, however, it is the secondary sulphides of silver and copper, and the complex sulpho-salts, rather than the free metals, which are the most important secondary minerals. Attempts to form copper and silver sulphides from dilute acid solutions, under conditions like those assumed to exist where these metals are forming enriched sulphides, have been singularly disappointing, although a large number of combinations of solutions and minerals have been tried and in some experiments the action has been watched 18 months. Thus far I have obtained no extensive pseudomorphous replacement, though I hope, by exposing the material for a longer time and using alkaline as well as acid solutions, that I may do so. Disappointment also resulted from attempts to form sulphides by evolving H_2S from minerals by the action of solutions of such concentrations as are known in mineral waters.

On the other hand, if these common minerals (pyrite, chalcopyrite, sphalerite, pyrrhotite, stibnite, etc.) are treated with a dilute alkaline solution, and if to the resulting solution an acid solution of silver or copper is added, the sulphides of these latter metals are readily precipitated. With arsenic, antimony, or iron in the alkaline solution, mixed sulphides form. May we not as-

sume that conditions favor reactions of this sort where sulphide ores are being altered by superficial processes? It is apparently well established that in the upper or oxidized portions of sulphide deposits the solutions are predominantly acid sulphate solutions. In depth where atmospheric oxygen is excluded and where minerals containing alkalies are predominant, the solutions are alkaline. There must be a zone where, if there is any circulation of solutions, the acid and alkaline solutions will mingle. Is it not rational to suppose that in some deposits, a large part of the secondary sulphides may be precipitated where the descending acid metalliferous solutions encounter the alkaline solutions which are known to be there?

It is a pleasure here to give special thanks to Dr. Emmons, without whose kindness and very practical assistance this paper would not have been possible.

THE GOLD OF THE SHINARUMP AT PARIA.

ANDREW C. LAWSON.

INTRODUCTION.

The strata of the Plateau Province which lie between the Aubrey limestone and the Vermilion Cliff sandstone were designated by Powell[1] the Shinarump Group. The same classification was adopted by Gilbert.[2] Both authors placed the group in the Jura-Trias and recognized in it three formations. Powell divided the group into Lower and Upper Shinarump with an intervening conglomerate varying from 20 to 200 feet in thickness, the "Shinarump Conglomerate," and placed the total thickness of the group at 1,800 feet. Gilbert's description of the three formations at the Henry Mountains is as follows:

SHIN-AR-UMP GROUP.

a.	Variegated clay shale; purple and white above and chocolate below with silicified wood	300 feet.
b.	Gray conglomerate, with silicified wood; the "Shinarump Conglomerate".....	30 feet.
c.	Chocolate-colored shale, in part sandy...	400 feet.

Dutton[3] in his account of the Geology of the High Plateaus of Utah used the same nomenclature, but stated that the age of the Shinarump is either Permian or Lower Triassic. He characterized the Shinarump as:

"in some respects the most extraordinary group of strata in the West, and perhaps the most extraordinary in the world. To the eye they are

[1] "Geology of the Uinta Mountains," 1876, pp. 41, 68.
[2] "Geology of the Henry Mountains," 1877, p. 6.
[3] "Geology of the High Plateaus of Utah," 1880, p. 144, et seq.

a never failing source of wonder. There are especially three characteristics, either one of which would render them in the highest degree conspicuous, curious, and entertaining. First may be mentioned the constancy with which the component members of the series preserve their characters throughout the entire province. . . . A second striking feature is the powerful coloring of some of the beds. . . . Maroon, slate, chocolate, purple and especially a dark brownish red (nitrous acid color) are the prevailing hues. . . . It is in the middle members that they are so resplendent. Alternate horizontal belts of varying tones and shades, not merging into each other by gradation, but like ribbons joined at their edges, are seen wherever the formation is exposed in the same general vertical succession, and give the Shinarump Cliffs an aspect most constant, peculiar, and wholly unlike any others. . . . Probably the most striking characteristic of this formation is to be found in the architectural forms which have been carved out of it by the process of erosion."

Two years later Dutton[1] placed the Lower Shinarump of Powell in the Permian on the basis of fossils discovered by Walcott in 1879, who also found that the "Shinarump Conglomerate" rests unconformably upon the Permian beds although without any discordance of dip.

Since then the term Shinarump has been restricted to the strata between this unconformity and the Vermilion Cliff sandstone, and Davis[2] appears to be inclined to restrict it still farther to the conglomerate. These two groups, the Shinarump and the Vermilion Cliff, are now recognized as constituting the Triassic of the Plateau Province.

The term Shinarump as here used applies to both the basal conglomerate of the Triassic and to the variegated strata above it, up to the base of the Vermilion Cliff sandstone. For the sake of distinction the one will be referred to as the Shinarump conglomerate or sandstone and the other as the Shinarump clay. It is the purpose of this paper to record some facts of interest with regard to the Permian and Shinarump formations as gold bearing deposits and incidentally to contribute some observations upon the stratigraphy of the section at Paria.

[1] "Tertiary History of the Grand Cañon District," 1882.
[2] "An Excursion to the Grand Canyon of the Colorado," 1901, p. 116.

PHYSICAL FEATURES.

Paria is a settlement on a flood plain of the Paria River now consisting of one family which maintains a post office for the convenience of the sheepherders of the region. It is situated about midway between Lee's Ferry at the head of the Marble Cañon and Canonville in Southern Utah. To the north and south of Paria the river flows through a narrow cañon with precipitous walls, but at Paria the course of the stream is in the Shinarump clay for about three miles and in this stretch it has,

FIG. 32. General view of Shinarump clays with Vermilion Cliff sandstones above. Looking west from Paria flood plain north of Paria.

by horizontal corrasion, evolved a conspicuous flood plain having a maximum width of about half a mile. On the northeast side of the flood plain the Shinarump clay forms a buttressed pedestal about 400 feet high, upon which rests the massive, bright red sandstone of the Vermilion Cliff. The total height of the scarp is probably about 800 feet and its upper half is vertical. The lower half of the scarp, forming the pedestal, is a curiously

sculptured slope having a width at the southeast near Paria of from 400 to 500 feet, but widening toward the northwest to about 3,000 feet. The slope is dissected by numerous steep gulches which head up to the base of the vertical cliff; and these have tributary gulches. The areas bounded by the drainage lines of these gulches are shaped in smooth, steep-sided, bare domes. The surface of the slope is thus remarkably mammillary, and presents a type of erosional form which is quite characteristic of the Shinarump, although it has been scarcely alluded to in the numerous descriptions of the physiography of the Plateau Province. The architectural forms described by Dutton[1] as characteristic of the Shinarump appear to be those due to the sculpture of the Permian, and his descriptions were written at a time when the Permian was included in the Shinarump Group. In his later book[2] in which the Permian was separated from the Shinarump the sculptural forms of the Vermilion Cliff sandstone overshadowed the forms peculiar to the underlying Shinarump and prevented their due recognition.

On the southwest of the Paria flood plain the Vermilion Cliff sandstone has been removed except for one isolated butte about 40 acres in extent; and the relief is determined by the peculiar mammillary or domed forms of the Shinarump clay. The breadth of the clay on this side of the river is about 4,000 feet. At its southwestern margin the clay is seen in fine exposures to rest upon a light gray sandstone, with a gentle northeast dip. This sandstone being more resistant than the clay projects generally beyond the limit of the latter as a well defined backward sloping bench.

To the southwest of the Shinarump extends the Permian, the upper surface of which forms a gently sloping plateau on the flank of the East Kaibab monocline. The plateau is intricately dissected by innumerable narrow, vertically walled cañons, so that it is practically impossible to traverse it. Still farther to the southwest, this sloping plateau of Permian strata ends at an escarpment

[1] "Geology of the High Plateaus," p. 145 and Plate X.
[2] "Tertiary History of the Grand Cañon District," 1882.

overlooking the top of the Aubrey limestone as it bends up in the great monocline.

Stratigraphy.—In the plateau province he who runs may read the sequence of formations. In my own case the pleasure of the reading was drawn out in a leisurely walk of 80 miles from Lee's Ferry to Paria by way of House Rock Valley. Along this route the great roll of the East Kaibab monocline is splendidly revealed in the surface of the Aubrey limestone, where it has been stripped of its covering of Permian and later strata. In the descent from

FIG. 33. Showing residual butte of Vermilion Cliff sandstone resting on Shinarump clays on west side of Paria flood plain.

the head of House Rock Valley to Paria the Permian is exposed from top to bottom in the winding cañon followed by the wagon road. It consists of several hundred feet of thinly bedded, red mud shales, and sandy shales. In its lower and middle part the strata are traversed by innumerable narrow gash veins of gypsum. These range usually of from an inch to an eighth of an inch in thickness, and lie nearly flat, but generally at a small angle with

the bedding. The aggregate of these veins is in several instances observed, from 5 to 10 per cent. of the total volume of the beds. The unaltered and slightly disturbed condition of the strata raises a curious question as to the forces concerned in opening the spaces in which these nearly flat but oblique veins lie. Stresses connected with the monoclinal folding of the region may be invoked to explain the orientation of the cracks, but the crystallization of the gypsum itself was probably a large factor in the distension of the walls.

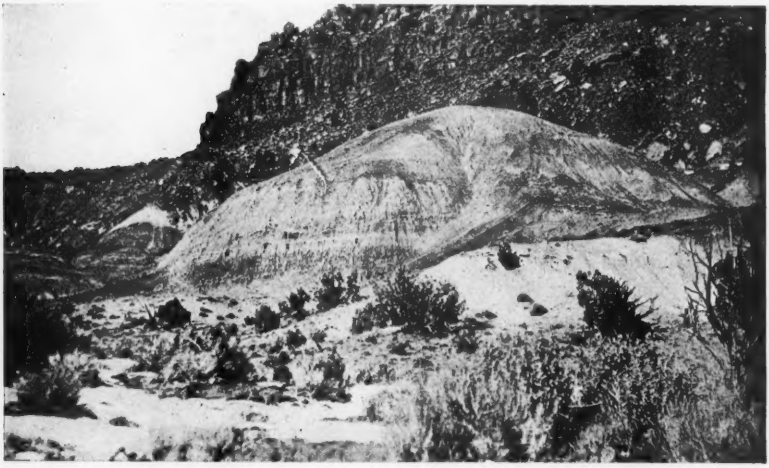

FIG. 34. Showing detail of erosional forms of the Shinarump clay just below the Vermilion Cliff sandstone on east side of residual butte near Paria.

In the upper two or three hundred feet of the Permian section the gypsum veins are not notable features of the cañon walls. The latter are variegated in color, however, by the intercalation of thin beds of green shale with the prevailing red beds. The green beds make up about 10 per cent. of this portion of the Permian section. The uppermost bed of the Permian is distinct

from all below it in that it is a persistent stratum of hard, massive red-brown sandstone from 10 to 20 feet thick.

Resting on the Permian is the basal formation of the Shinarump group. The superposition is well exposed along a N.W.–S.E. line of contact less than a mile southwest of the Paria River at Paria. The basal formation is from 30 to 50 feet thick and is a rather coarse-textured, light gray sandstone, which is in some parts pebbly, and which contains numerous fragments of silicified wood. The stratigraphic relation of sandstone to the underlying Permian is described by Walcott[1] as unconformable. The erosional break figured by him is very plain at one locality, but as he points out it involves no essential discordance in the dip of the two formations; so that it is not easily detected elsewhere.

The clays of the Shinarump which rest on this basal sandstone are the most interesting feature of the section. They have a maximum thickness of about 400 feet, on the northeast side of the Paria, but appear to be considerably less than this in the section through the butte on the southwest side, where the complete section of the beds between the Permian and the Vermilion Cliff sandstone is revealed.

The stratification of the Shinarump clays is not less remarkable than their erosional forms. Viewed at a distance the formation is seen to consist of thick layers of different colors sharply marked off one from another. One or two beds of sandstone occur in the sections, but with this exception the diversely colored layers are homogeneous as to texture and resistance to erosion; so that the bedding planes do not mark any break or interruption of the profiles of the domes into which the whole formation has been carved. The colors of the beds have been subdued by weathering, so that the strong deep tones seen in fresh cuts appear as faded and harmonious tints on the natural slopes. The general effect is that of a pleasing gray relieved by thick horizontal bands of pink, chocolate, maroon, green, purple, black and white, but the gray tints prevail in the lower part of the section and the reddish tints in the upper part. When these strata are trenched below the

[1] *Bull. G. S. A.*, Vol. I., pp. 63–64.

weathered surface layer, however, it becomes apparent that the distinctions of color are not so sharp as the distant view suggests. There are frequent gradations by intercalation of one colored clay with another. These gradations involve the alternation of gray and red, red and green, gray and purple, or red and purple layers. Several of the strongly marked bands of the section which appear as a single tint on the weathered slopes are in

FIG. 35. Showing detail of erosional forms of the Shinarump clay, below the Vermilion Cliff sandstone near Paria.

reality an alternation of layers of two different colors from top to bottom; in others one color predominates in the bottom part and another in the upper part. The weathering and the surface creep have blended these into one tint. In other cases, however, the bands have a uniform color throughout as seen in trenches.

Three sections of the Shinarump clays were examined in great detail by cutting trenches in the face of the slopes. One of these was chosen on the northeast side of the Paria flood plain, one on

the southwest side and the third on the southwest margin of the formation where it overlooks the Permian plateau. The sections were thus about half a mile apart and on a line transverse to the strike of the formation.

The first mentioned trench was a continuous cut from the level of the river up to a point 210 feet above it across the edges of the strata in the middle part of the formation. The second was similarly cut from the level of the river across 174 feet of the lower part of the formation. The third was cut from the top of the basal sandstone across 240 feet of the clays, or about two thirds of the total thickness in this section. The measurements of the beds in these trenches afforded an exact section of the Shinarump as far as they extended, but as the measurements had to do merely with color distinctions, the character of the beds being for the most part otherwise identical, I shall here refer only to certain special features. In the most southwesterly section a two foot bed of light gray, medium-textured sandstone was encountered interrupting the continuity of the clays at 110 feet above their base. Above this the clays are sandy for several feet. Half a mile to the northeast, in the middle section, a bed of similar sandstone 15 feet thick occurs, the base of which is 125 feet above the Paria flood plain. Half a mile to the northeast, in the remaining section, this same bed of sandstone has expanded to a thickness of 50 feet of soft sandstone with a layer of 2 feet of hard sandstone at its base. Above the 50 foot bed of sandstone, after an interval of 9 feet of red and purple clays, is another bed of sandstone, 4 feet thick, which is much harder than the thick bed below. Along the northeast side of the Paria these sandstones are prominent features of the Shinarump section and form a notable interruption in the otherwise smooth profiles of the clays. In the most southwesterly section a four foot bed of black clay occurs 23 feet above the sandstone last described and is succeeded by green clay. In the middle section this black clay is 10 feet thick and contains lenses of chert. It is here succeeded by a bed of hard sandstone 2 feet thick, which causes a notable interruption in the otherwise smoothly domed profiles of the formation. This

black clay is missing in the section on the northeast side of the Paria.

Besides these variations in the stratigraphy of the Shinarump clays it is also apparent that the colored bands, which appear so uniform in particular sections, are not persistent; but that in the same stratigraphic horizon the colors are to a considerable extent interchangeable.

Throughout the clays of the Shinarump there are numerous irregularly nodular concretions consisting almost wholly of carbonate of lime and magnesia. These have diameters ranging up to about 2 inches, but most of them measure less than an inch across.

On top of the Shinarump clays lies the massive, red Vermilion Cliff sandstone splendidly displayed in a vertical cliff on the northeast side of the Paria to a thickness of about 400 feet. The change from the clays to the sandstone is abrupt, and there is little or no evidence of the transitional gradation which Dutton has observed at this contact in other parts of the Plateau Province.

Structure.—All of the strata at Paria from the Permian to the Vermilion Cliff sandstone, inclusive, are situated on the lower flank of the great East Kaibab monocline, and the prevailing dip is, therefore, to the northeast at low angles. There is, however, on the flank of the monocline a low anticlinal fold the axis of which lies in the Paria flood-plain. This is clearly shown by the opposing directions of dip on the two sides of the river, as indicated in the accompanying

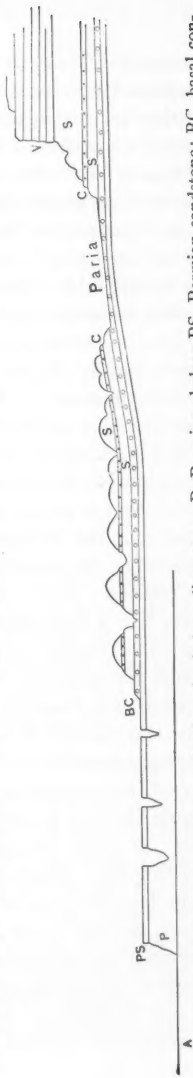

FIG. 36. Transverse section at Paria. A, Aubrey limestone; P, Permian shales; PS, Permian sandstone; BC, basal conglomerate and sandstone of Shinarump; S, Shinarump clays; C, sandstone bed; V, Vermilion Cliff sandstone.

cross-section (Fig. 36). The relation of this anticline to the exceptional amount of erosion at Paria suggests the interesting question as to whether it may be due to an upwarping of the strata due to relief of load.

Physical and Chemical Properties of the Clay.—One of the most striking properties of the Shinarump clay is its behavior in water. Samples of the clay taken in the field are usually moist and the amount of water which may be driven off at 105° C. is very considerable. But when a fragment of the clay is immersed in water it immediately swells enormously and breaks down rapidly into an incoherent flat cone. When this material is examined microscopically it appears to be composed almost wholly of a colloidal substance with a very small admixture of fine silt and some concretions of carbonate of lime and iron oxide. The swelling and slacking of the clay in water is probably due to the colloidal absorption of water. The mixture is in such a fine state of division that it passes freely through filter paper. This peculiar behavior of the Shinarump clay is in marked contrast to other sedimentary clays, such, for example, as the clay of the delta of the Colorado. At the time of the break of the Colorado river to Salton Sea a few years ago the river, flowing down the steep slope of the delta, scoured out a deep, wide, cañon-like trench through the upper 40 feet of the delta silts; but the downward corrasion was checked at Calexico by a stratum of blue clay which was so tenaceous that it effectively resisted the powerful scouring action of a swift river. In contrast to this behavior the clays of the Shinarump require only to be sprinkled with water to cause them to promptly disintegrate and flow freely with the water. It is this behavior with water that has led to schemes of extracting their gold content by hydraulic methods. With rocks of this kind the rate of erosion, other things being equal, must increase as some large function of the increase of rainfall. If we assume that in Quaternary or Pleistocene time the rainfall of the region was x times greater than at present the rate of denudation was doubtless x^n times greater where n is no small figure. At present the rainfall is slight and the result is that the clays

have been superficially disintegrated to a depth of from one to two feet. The swollen clay of this surface layer dries out and becomes a loose, fluffy pulp of extreme lightness, softness and incoherence. At times of heavy rains, such as occur occasionally on the desert, this material is washed down to the river in enormous quantities. It was found by experiment that swiftly running water carries in suspension about 30 per cent. of its weight of dry pulp.

A sample of the gray Shinarump clay from Lee's Ferry was submitted to chemical analysis by Prof. W. C. Blasdale with the following result.

SiO_2	53.45
Al_2O_3	18.56
Fe_2O_3	7.89
CaO	1.87
MgO	1.66
H_2O @ 105° C.	6.77
Ignition Loss above 105° C.	7.26
	97.46

There are also small amounts of carbonates and sulphates soluble in water in the clay. In it most of the iron is present in the form of minute concretions of limonite and the lime and magnesia are in the form of carbonates. If we deduct these together with the corresponding amounts of H_2O and CO_2 and reduce the balance to percentages we get the following results:

$$SiO_2 = 71.6, \qquad Al_2O_3 = 24.9, \qquad H_2O = 3.5.$$

From this it appears that the ratio of silica to alumina is nearly 3:1, which is far greater than should be the case if the clay, deducting the concretions above referred to, were composed wholly of kaolin. There is not sufficient quartz present to account for the excess of silica. The proportion of water present is also much too small for kaolin. It seems probable, therefore, that a considerable proportion of the flocculent colloidal substance seen under the microscope is in reality silicic acid, and that the presence of silica in this form may account for the peculiar behavior of the clay with water.

Gold Content.—The Shinarump clay contains gold and ineffective attempts have been made to mine it at a profit by the hydraulic method. The purpose of my examination of the sections at Paria was in part to determine the quantity of gold present. The trenches in the three lines of section above referred to were made in the course of sampling the deposit. The nearly horizontal attitude of the beds made it possible to sample the clays by vertical cuts on the face of the bare hill slopes. The cuts were made deep enough to get beneath the veneer of slackd pulp which covers the unweathered clay. A sample of from 25 to 30 pounds was taken every ten feet measured vertically by leveling. The sampling was done on the assumption that whatever gold the clay might contain was all very fine, and practically uniformly disseminated in any given stratum. The lower part only of the formation was sampled, comprising from one half to two thirds its entire thickness. The samples after careful crushing and quartering were submitted to Mr. E. H. Simonds, of San Francisco, for assay. This he did with the utmost care, in quadruplicate for each sample.

The first series of 18 samples were taken from a trench 174 feet high on the southwest side of the Paria River. Of these one was found to contain 10 cents per ton, nine 5 cents per ton, two 2½ cents per ton, four contained a trace and one contained none. These results were checked by taking an aggregate made up of equal weights of every one of the 18 samples. The assay of this aggregate sample was 5 cents per ton. It is worth noting that the sample which yielded 10 cents per ton was taken from the 15 foot bed of sandstone described as occurring in this section.

The second series of 22 samples was taken from a trench 210 feet high on the northeast side of Paria. Of these one yielded 12½ cents per ton, two 7½ cents, eight 5 cents, five 2½ cents, five a trace and one none. The average of the entire cut is about 4 cents per ton.

The third series of samples was taken from a trench 240 feet high beginning at the top of the Shinarump sandstone on the southwest margin of the formation. Of these one yielded 7½

cents per ton, five yielded 5 cents, one 2½ cents, sixteen a trace and one none. Confirming these results an aggregate of equal amounts of 13 samples from the first series of 18 yielded to assay by Mr. W. S. Morley 4 cents in gold per ton. A similar aggregate of 16 samples from the second series yielded Mr. Morley 2 cents per ton; and an aggregate of 20 samples from the third series yielded also 2 cents per ton. Comparable results are obtained by amalgamation assays on large samples using chemically pure mercury.

To those unfamiliar with the hydraulic method of mining the gold content of the Shinarump clays may appear to be so small as to be insignificant and unworthy of attention from a practical point of view. But under the most favorable conditions gravel containing 5 cents per yard or about 2½ cents per ton may be worked at a profit. The peculiar way in which the Shinarump clay slacks and runs with water suggests that it may be no less susceptible of hydraulicking than banks of gravel. This suggestion coupled with an exaggerated notion of the amount of gold contained in the clays has led to various attempts to exploit them for gold. The ground has been staked out in hundreds of placer claims and these have been offered for sale at large figures. The value of the ground is, however, very problematical. If a method of successful hydraulicking and recovery of the gold be developed it will only be after a long period of experimentation, at large expense, at a few favored localities where a vast yardage of the clays is free from overburden, and where abundant water may be had cheaply. No large expenditure for the acquisition of territory would be justified until the method of winning the gold has been demonstrated.

At present the occurrence is interesting from a geological rather than a practical point of view. We may safely assume on the basis of the sampling at Paria that the Shinarump clay there contains on the average 5 cents per cubic yard. The same formation appears to be similarly auriferous at Lee's Ferry and at San Juan; and it is probable from the extreme uniformity in the physical characteristics of the formation wherever it has been

observed, that it is similarly auriferous throughout its extent. The formation underlies a territory of about 100,000 square miles and its average thickness may be placed at 300 feet. Reckoning 5 cents to every cubic yard of this ground the gold content of the Shinarump clay is about $1,500,000,000,000! All of which goes to show that universities should not despair of some day securing an adequate financial endowment.

But the gold is not confined to the Shinarump clays in the Plateau Province. A cut 140 feet high was made in the underlying Permian shales and 14 samples secured for assay. Of these two yielded 10 cents in gold to the ton, five yielded 5 cents, six a trace and one none. An aggregate of equal parts of these 14 samples yielded to an amalgamation assay 4 cents per ton. This result is probably representative of the gold content of the entire thickness of the Permian, since the conditions of sedimentation appear to have been very uniform throughout. The Permian beds do not, however, slack in water, and there is no prospect of their being susceptible of hydraulic mining. They are, however, quite as interesting as the Shinarump as an instance of the occurrence of gold in fine grained sedimentary rocks.

PLATE VIII.

PLATE VIII.

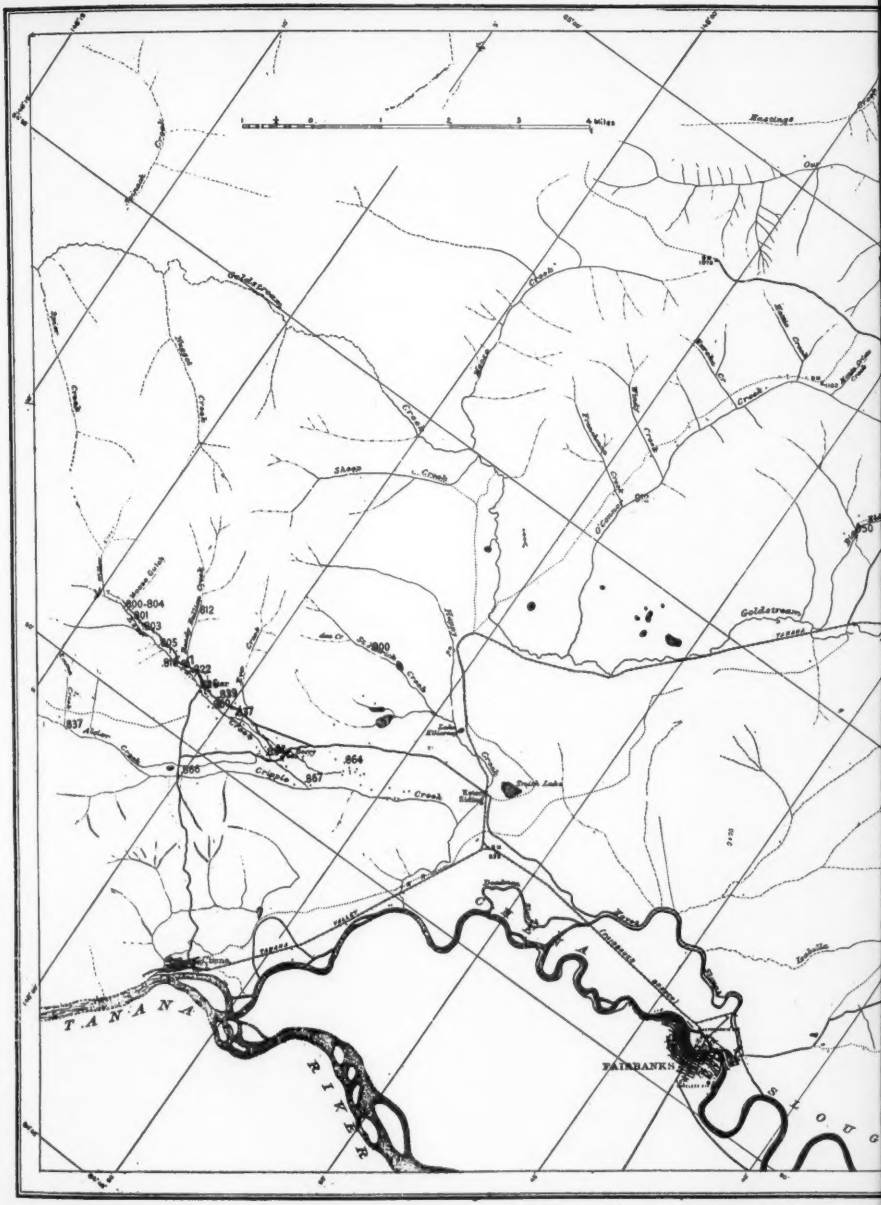

PLATE VIII. DRAINAGE MAP OF FAIRBANKS REGION, ALASK

Note.—Figures preceded

S REGION, ALASKA, INDICATING THE LOCATION OF PLACERS AND LODES AND THE FINENESS OF THE GOLD DERIVED THEREFROM. (BASE USED ALASKA SHEET 6424, U. S.

ures preceded by an x are the fineness of the bullion from the lodes. The other figures are the fineness of the bullion from the placers.

Coffee Dome
Creek
Gulch
Fork
Hill
Ridge
Bench
Flat
Gulch
Creek

THE FINENESS OF GOLD IN THE FAIRBANKS DISTRICT, ALASKA.[1]

PHILIP S. SMITH.

Placer gold is generally believed to increase in fineness the farther it is removed from the parent vein. This assumption is theoretically sound and is based on field evidence, but in geologic publications surprisingly few detailed facts are recorded in its support. A statement of the fineness of the placer gold found on the creeks in the Fairbanks region, Alaska, together with the location of the known lode mines and prospects and the fineness of the lode gold may therefore be of service. Data concerning the fineness of the Fairbanks gold were furnished by Mr. Frank W. Hawkins, formerly assayer for the Washington-Alaska bank of Fairbanks, who has made many thousand determinations of fineness and through whose courtesy the records were made available.

Plate VIII. indicates the location of the placers and lodes and shows by figures the fineness of the gold. This map is practically self explanatory but certain of the less obvious facts are noted in the following statements.

The placer gold having the highest fineness in this district assays 950 and is found on claims in the central part of the valley of Big Eldorado, a tributary of Goldstream. The lowest fineness recorded for any considerable amount of placer gold is 800, from claims near the head of Ester Creek and on St. Patrick Creek, both of which are tributaries of Cripple Creek. Prindle and Katz,[2] however, reported that the average value of the gold from Ready Bullion Creek, as determined by 8 assays, is $16.38 an ounce, which is equivalent to a fineness of 792½. The average of the 167 determinations recorded on the map (Plate VIII.) is 880.

[1] Published by permission of the Director of the U. S. Geol. Survey.

[2] Prindle, L. M., and Katz, F. J., Geologic reconnaissance of the Fairbanks quadrangle, Bull. U. S. Geol. Survey No. 525, 1913.

This average is, of course, not the average of all the gold produced, for all determinations were given equal weight in computing the average, whereas to obtain the correct fineness for the district the amounts of gold of each fineness should be considered. According to 353 assays listed by B. L. Johnson and published in the report by Prindle and Katz the average fineness of the gold, computed in the same way as the above, is 857. The mean of the two averages is 868½.

The assayers at Fairbanks generally compute the silver in bullion by assuming that the difference between 990 and the determined fineness of the gold is silver. On this basis, according to the recorded figures, silver forms about 110 parts of each thousand parts of bullion. Prindle and Katz stated that in 7 of the assays they collected the silver had been actually determined and ranged between 82 and 172 parts per thousand. The mean of these extremes is 127.

Twenty-four determinations of the fineness of the lode gold from different parts of the Fairbanks region were obtained and the average for each mine is recorded on the map (Plate VIII.). The highest fineness is 843, the lowest is 780½, and the average of the 24 determinations is 817, which is equivalent to a gold value of $16.89 per ounce. The average lode gold is therefore 63 parts per thousand lower than the average placer gold reported in this paper or 40 parts per thousand lower than the fineness reported by Prindle and Katz. The amount of silver was determined in 5 of the assays of the lode gold bullion and ranged from 149 to 180 parts in a thousand parts of bullion, the average being 167½. The average silver content of the bullion from all the lodes computed as the remainder obtained by subtracting the fineness of the gold from 990, is 174½.

The silver in the bullion from the lodes, as determined from the figures given in the preceding paragraph, is therefore from 57½ to 64½ parts per thousand more than in the bullion from the placers, or from 40½ to 47½ parts per thousand more than the average of the 7 assays of silver reported by Prindle and Katz. The average of these two sets of determinations indicates

that the bullion from the placers has an average silver content of about 52 parts per thousand less than that of the bullion from the lodes.

A comparison of the fineness of the bullion from the individual placer claims in the district indicates that on the whole the gold becomes progressively finer downstream. This fact is well illustrated by the bullion from Twin and Pedro creeks, for at the farthest claim upstream it is 861 fine and becomes progressively finer downstream until at the junction of Pedro and Gilmore creeks it is 906 fine. No lodes are being developed in the Pedro Creek basin but disseminated mineralization undoubtedly occurs there, so that the placer gold in this basin probably did not come solely from the lode deposits noted on the upper part of Twin Creek and Skoogy Gulch. This condition also prevails in all the other valleys. The data therefore do not warrant computations based on the assumption that all the gold is derived from the same source.

Although it is recognized that the gold from all parts of the same stream did not come from the same source, some suggestive data were obtained by computing the increase in fineness per mile of several of the more productive streams. This rate was found by dividing the difference in the recorded fineness of gold from the headmost and lowermost recorded placer locality by the distance between the two stations. The figures obtained were necessarily qualitative rather than quantitative, but on this basis the average increase in fineness for each linear mile on Fairbanks, Cleary, Dome, Pedro, Eldorado, and Ester creeks was respectively 3, 6, 6½, 12½, 13, 21. Part of the variation between these figures is probably to be explained by the relation of the trend of the valleys to the trend of the belt of mineralization. For instance, Fairbanks Creek from its head to Deep Creek lies in the belt of mineralization, so it receives accessions of gold all along this part of its course and for that reason the fineness of its gold changes least rapidly.

A slow increase in fineness was noted also in the part of Cleary Creek above Wolf Creek. In places in this stretch the

bullion shows even a slight decrease in fineness downstream. Thus the bullion on Cleary Creek above its junction with Bedrock Creek and also above its junction with Chatham Creek is finer than at places immediately below these points. This is shown by a fineness of 850 above and 840 below the junction of Bedrock Creek and by a fineness of 844 above and 837 below its junction with Chatham Creek. This decrease is undoubtedly attributable to the large amount of low grade gold brought in by the side streams from the various lodes in the lower portions of Bedrock and Chatham creeks. North of Wolf Creek the course of Cleary Creek lies outside the general belt of mineralization. In this stretch the fineness increases much more rapidly and uniformly, the average rate being about 12 parts per mile. This rate, however, is not entirely the result of refinement through transportation for some gold of low fineness has undoubtedly been derived from undiscovered lodes or from areas of disseminated mineralization.

Eldorado and Dome creeks have two features in common with Cleary Creek already described, namely, their upper parts trend nearly parallel with the belt of mineralization and their lower parts are transverse to it. The increase in fineness in the part of Eldorado Creek which is parallel to the belt of mineralization is about 6 thousandths per mile whereas in the transverse section it is 14 thousandths per mile. The placer deposits on Dome Creek differ from those on the streams already described in that for a considerable distance the pay streak is deep and is not directly affected by the present stream.

No satisfactory explanation of the great increase downstream in the fineness of the gold from Ester Creek has been found. The headward part of Ester Creek as far as Eva Creek is transverse to a mineralized belt about 2 miles wide, but the lower part is incised in thick gravel deposits of complex origin and history. Probably much of this older deposit was not derived from local sources and therefore its gold has also undergone longer transportation. Even in the part of Ester Creek valley between Moose Gulch and the town of Ester, where the creek cuts auriferous

stringers in rather close succession, the change in fineness increases at the rapid rate of 16 thousandths a mile. At first it was believed that this part of Ester Creek valley, although transverse to the belt of mineralization, would have features similar to those of a valley parallel with the belt, that is, the fineness would change relatively slowly. When this conclusion was found to be incorrect the best explanation seemed to be that even a short distance between mineralized areas is sufficient to allow a great amount of natural purifying of the bullion.

Although generally an increase in the fineness occurs toward the lower part of the streams, several exceptions to this rule were recognized. Treasure Creek affords the most notable recorded instance of an increase of fineness upstream. Half a mile above the junction of this stream and Vault Creek the bullion is 897 fine; near the mouth of Independence Creek, three quarters of a mile farther upstream, it is 904 fine, and still farther upstream is 906 and 910 fine. This anomaly is partly explained by the fact that the placers farthest up Treasure Creek are deep and that their history is probably different from that of the present creek placers. The increase upstream, however, is probably due in part to a belt of mineralization, trending nearly east and west, that crosses Treasure Creek a short distance above Independence Creek. According to this interpretation the gold on the highest recorded placer claim was probably derived from unknown mineralized areas farther upstream, whereas the gold below this claim is a mixture of this gold with that of lower fineness which has been derived without much transportation from veins in the neighborhood.

The fineness of the gold probably increases even in deposits which are not being transported; in other words, probably the longer gold is subjected to surface processes, other conditions being constant, the finer it becomes. Therefore, in two deposits alike in all features except those due to difference in age, the older contains gold of the higher fineness. Search among the records of the fineness of gold from Fairbanks for detailed evidence in support of this belief so far has proved unsuccessful,

for too many of the factors are unknown. A comparison of the average fineness of the gold from the Fairbanks placer deposits of Pleistocene-Recent age with that of the gold from the Tertiary gravels of California of Tertiary age, while quantitatively inexact, affords some suggestive data bearing on this question. According to Lindgren[1] ". . . in the main Tertiary streams a considerable refining of the gold has been going on, so that the average grade [fineness] is now decidedly above 900," whereas, as previously stated, the average bullion from the Fairbanks placers is not over 880 fine. The fineness of the lode gold from which the Tertiary placers were formed is not known accurately but Lindgren[2] gives the following figures for the fineness of the gold from certain of the California quartz mines.

FINENESS OF GOLD FROM CALIFORNIA QUARTZ MINES.

Location.	Highest.	Lowest.	Mean.
Plumas County	850	627	738
Sierra County	883	622	752
Nevada County	890	645	768
Placer County	921	580	750
Eldorado County	901	570	735
Calaveras County	975	627	801
Average	903	612	757

The average mean of these records is 757, which, though quantitatively inaccurate because figured on the assumption that the average fineness is the mean of the extremes, indicates that the California lode gold is probably not so fine as the average Fairbanks lode gold, the latter according to the few records available having a fineness of 817. The difference between the fineness of the Tertiary placer gold of California and that of the Pleistocene-Recent placer gold of Fairbanks can not be attributed therefore to the higher original fineness of the California lode gold.

[1] Lindgren, W., "Tertiary Gravels of the Sierra Nevada of California," Prof. Paper U. S. Geol. Survey No. 73, 1912, p. 69.

[2] *Op. cit.*, p. 68.

THE VADOSE SYNTHESIS OF PYRITE.

ALFRED R. WHITMAN.

The experiment here described was undertaken to determine whether it would be possible to reproduce in a laboratory the essential conditions of vadose circulation, and obtain thereby the oxidation, solution, transportation, reduction, and re-deposition of pyrite.

Origin of Experiment.—In the fall of 1910 and the spring of 1911, the writer investigated the pyrite deposit at Leona Heights owned by the Leona Chemical Co., for the purpose of determining its genesis. The conclusion was reached that it originated through processes similar in character to those producing secondary sulphide enrichment in ore bodies which have been long exposed to vadose circulation. In order to obtain more general evidence of the validity of this idea, it was conceived that a synthetic inquiry into the geo-chemical processes involved might shed light on the subject; and with this in view the experiment was undertaken.

In the study of the Leona Heights pyrite deposit, it was found that the ore body is a large, irregular, potato-shaped mass of nearly pure pyrite, entirely inclosed in a country rock of acidic porphyry, consisting chiefly of rhyolitic and andesitic lava flows, all of which contain disseminated pyrite in fine specks and irregular grains. This country rock is much jointed and the microscope shows also that it is much altered. The alteration appears to be quite uniform throughout the mass, the fine-grained ground-mass being changed largely to kaolin, the feldspar phenocrysts altered on their peripheries and often throughout to kaolin, and the ferromagnesian minerals to chlorite. The contacts of the ore body with the wall rock are generally sharp and determined by the joint planes of the walls, indicating its origin subsequent to the greater part at least of the jointing.

Under the microscope these contacts are very instructive. It appears that the alteration of the wall rock has progressed along anastomosing channels between the phenocrysts, giving a thin section a mottled appearance. This same mottled structure is clearly seen in the ore adjacent to the contact, and, in fact, characterizes it throughout. Fine threads of pyrite grains emanate from the main mass and ramify outward along the channels of alteration, inclosing and finally replacing the island-like blotches of more resistant material; and immediately adjacent to the contact the alteration is most complete and the kaolin most abundant.

This makes it appear that the alteration of the rock preceded the formation of the ore body, and that it was due to acid solutions which were more concentrated, or more potent to produce kaolin from feldspar immediately adjoining the mass of ore as it grew. It also appears that the ore was developed by a metasomatic replacement of these alteration products. Perhaps this latter process amounted essentially to the solution and removal of the kaolin by sulphuric acid liberated through the formation or precipitation of pyrite on the periphery of the ore body.

These ideas may perhaps be expressed more clearly by the following hypothetical equations:

(1) $2FeS_2 + 2H_2O + 7O_2 = 2FeH_2(SO_4)_2$,

(2) $15FeH_2(SO_4)_2 + FeS_2 = 2FeS_2 + 7Fe_2(SO_4)_3 + 7H_2SO_4 + 8H_2O$,

(3) $4KAlSi_3O_8 + 3H_2SO_4 + 8H_2O = H_4Al_2Si_2O_9 + Al_2(SO_4)_3 + 2K_2SiO_3 + 3H_2SiO_3$,

(4) $H_4Al_2Si_2O_9 + 3H_2SO_4 = Al_2(SO_4)_3 + 2H_2SiO_3 + 3H_2O$.

As a further evidence of the vadose origin of the deposit it was observed that the wall rocks were mineralogically the same whether near the contacts or remote from them, indicating that the solutions which produced the deposit were not different from those which produced the alteration of the inclosing rock. Were the solutions ascending it would be expected that they would produce a maximum of alteration along the main channels of ascent,

which would give a less uniform alteration of the country rock than is actually found.

These facts were interpreted to indicate that the pyrite disseminated through the rhyolitic country rock had, during the secular decay of that rock, been oxidized into acid ferrous sulphate or ferrous sulphate and free sulphuric acid, which had in part remained at the surface producing hematite and bleaching the rock, and in part had been carried downward by the vadose circulation to the ground water level. In its course it had altered the rock in the manner already described. Upon reaching the ground water level and a reducing environment, these solutions began undergoing reduction with the consequent precipitation of ferric sulphide or pyrite.

Work of Previous Investigators.—The process here outlined is essentially the same as that usually known as secondary sulphide enrichment. This subject has been studied in the field and laboratory by many geologists and geo-chemists and their data and conclusions agree in general with those outlined above. The first notable discussion was presented before the American Institute of Mining Engineers in 1900 by W. H. Weed.[1] In this paper Weed outlined the essential features of the process in such an accurate and thorough manner, that but little has been added to our understanding of it since then by other geologists, although much new evidence has been found, new applications made, and some of his ideas disproven.

He says in part:

> "In the present paper the writer will give a brief synopsis of this theory and will apply it more particularly to deposits of the precious metals, laying special emphasis upon the dependence of such enrichments upon the presence of iron sulphide (as pyrite, etc.) in the primary ore, and upon structural features which control the circulation of the enriching solutions below the water-level. It is believed that many, though not all, of the bonanzas and pay shoots of rich sulphide ores especially those carrying gold and silver which are encountered in ore deposits are of such secondary origin. . . . A legitimate deduction, too, is that such ore deposits decrease in value with depth.

[1] "The Enrichment of Gold and Silver Veins," Amer. Inst. Min. Eng., *Trans.*, Vol. 30, 1900.

"In an ore consisting of either one or all of the following sulphides:—pyrite, arsenopyrite, chalcopyrite blende, galena, tetrahedrite,—the minerals will oxidize according to their relative 'affinity' for oxygen, and inversely as their 'affinity' for sulphur. All the sulphides will be attacked simultaneously, but inasmuch as pyrite consists of four parts ferric and one part ferrous sulphide, and parts with a portion of its sulphur very readily, this mineral will be most attacked. This decomposes first to FeS and S. The sulphur usually forms H_2SO_4; the FeS forms $FeSO_4$. The latter changes to H_2SO_4, $Fe(OH)_3$ and $Fe_2(SO_4)_3$. The sulphuric acid attacks more iron sulphide and forms $FeSO_4$, together with H_2S—the latter in the presence of abundant oxygen forms H_2SO_4.

$$"5Fe_2(SO_4)_3 + Cu_2S + 4H_2O = 2CuSO_4 + 10FeSO_4 + 4H_2SO_4.$$

"The general order of attack of the suphides is therefore arsenopyrite, pyrite, chalcopyrite (FeS removed, leaving CuS) blende, galena, chalcocite, while tetrahedrite being a complex substance without definite percentage composition has no fixed place. Gold if present may be attacked by $Fe_2(SO_4)_3$ in which it is well known to be readily soluble, and silver goes into solution as sulphate.

$$"4CuSO_4 + 3FeS_2 + 4H_2O = 2Cu_2S + 3FeSO_4 + 2H_2SO_4 + 2H_2S + S.$$

"From the chemical reactions given, it is evident that enrichment is largely dependent upon the presence of marcasite, pyrite, or some other form of iron sulphide in the primary ore, since lixiviation depends upon the presence of the iron sulphates, and precipitation is mainly effected by the unaltered sulphides."

In 1907 Waldemar Lindgren, in a paper entitled "Ore Deposits and Physical Conditions,"[1] mentioned pyrite as one of the minerals occurring as a secondary sulphide originating from vadose circulation.

Spurr and Garrey[2] in 1908 in a paper on the Georgetown Quadrangle, Colorado, recognized pyrite as a product of vadose circulation.

In 1910 F. L. Ransome[3] started a long discussion in ECONOMIC GEOLOGY with a paper on "Criteria of Downward Sulphide Enrichment." Many geologists and chemists contributed to the dis-

[1] ECON. GEOL., Vol. 2, pp. 105, 1907.

[2] "Geology of the Georgetown Quadrangle, Colo.," U. S. G. S. Professional Paper 63, 1907.

[3] ECON. GEOL., Vol. 5, No. 3, 1910.

cussion, but little was added to the essential features of the process as stated by Weed ten years before. Some of the writers thought organic matter responsible for the precipitation of sulphides and some attributed it to hydrogen sulphide. Also some thought pyrite generally due to heated ascending solutions while marcasite was supposed to represent the FeS_2 precipitation from descending solutions.

In January of the present year C. F. Tolman, Jr.,[1] published in the *Mining and Scientific Press* a paper on "Secondary Sulphide Enrichment of Ores," in which he gave an excellently clear and comprehensive summary of the most advanced ideas on the subject and added many chemical details. As precipitating agents he mentioned carbonaceous matter, hydrogen sulphide, other metallic salts, and primary sulphides below ground water level; but he, as all the others, has ignored the possibility of kaolin playing a similar rôle.

The most important laboratory researches appear to have been begun in 1901 by H. N. Stokes.[2] In the bulletin on his researches he called attention to the more ready oxidation of marcasite over pyrite, the fact that ferric salts attack pyrite, and the fact that chalcopyrite is more easily attacked by ferric solutions than is pyrite. He also states that:

"There is no well established evidence of the existence of true paramorphs of pyrite after marcasite, or of marcasite after pyrite."

The experiments of Stokes on pyrite were continued in 1907 along somewhat different lines, and in a paper[3] published in ECONOMIC GEOLOGY he states:

"Without attempting to discuss the geological bearings, the results may be briefly summarized as follows: Pyrite and marcasite are decomposed by circulating alkaline waters which leave hematite or hydrated

[1] *Min. and Sci. Press,* January 4, 18, 25, 1913.

[2] "On Pyrite and Marcasite," U. S. G. S., Bull. 186, 1901.

[3] "Experiments on the Action of Various Solutions on Pyrite and Marcasite," ECON. GEOL., Vol. 2, 1907.

ferric oxide and carry away the sulphur in the form of alkali sulphides and thiosulphates. The sulphides may react in another place with metallic salts, giving sulphides; the thiosulphates may either remain unchanged or may react with copper or silver compounds, giving sulphides of these metals and alkali sulphates."

He also regards pyrite and marcasite as Fe_2S_3S.

In 1912, E. T. Allen[1] published a paper on "The Mineral Sulphides of Iron." He said in part:

"The pyrite of deep veins, metamorphic contacts, and hot springs as well as magmas, has been formed from hot solutions, and such solutions never contain strong mineral acids, but are generally if not always alkaline. The pyrite and marcasite of surface veins, on the other hand, are formed from cold solutions which often contain considerable sulphuric acid."

He made unsuccessful efforts to precipitate FeS_2 from a sulphate solution with organic matter, and concluded that H_2S was a far more promising agent, since it is quite common in nature. Acting upon this idea, he sealed ferric salts in a steel-incased glass bomb with H_2S and water; and after subjecting it to heat found that visible crystals of marcasite had been produced. As an explanation of this phenomenon he gave the reactions:

$$Fe_2(SO_4)_3 + H_2S = 2FeSO_4 + H_2SO_4^+S,$$
$$FeSO_4 + S + H_2S = FeS_2 + H_2SO_4.$$

Then on investigating to see why pyrite had not been formed, and under what conditions it could be formed, he concluded:

"It was therefore a plausible hypothesis that the concentration of acid influences the crystal form; it seems possible that pyrite might have formed in the earlier stages of the process when the acid was weaker."

This idea he subsequently proved by further experiment, finding that both pyrite and marcasite were originally produced, and that as the process continued with the increasing production of sulphuric acid, the pyrite decreased while the marcasite increased proportionately. He also found that the higher the temperature

[1] *Amer. Journ. Sci.*, 4th Ser., No. 33, 1912.

the more pyrite and the lower the temperature the more marcasite was produced.

In the reactions suggested above by the writer, accounting for the precipitation of pyrite by pyrite with the simultaneous removal of the adjacent aluminous wall rock, there is an incomplete precipitation of the iron carried in solution, the greater part of it escaping from the first reaction as ferric sulphate. Probably the reduction of this ferric salt to the ferrous condition would require the help of ferrous iron in the chlorite of the rock, hydrogen sulphide in the ground water, or organic substances carried down with it from the surface. But if these reducers were absent, it is possible that the present ore body represents less than one third of the total iron content of the vadose waters which brought it hither, the remainder being carried off to other regions by the slow circulation of the ground water.

Apparatus Used in the Experiment.—The apparatus used to test these ideas was arranged as follows: Ten glass tubes from two to four feet in length and an inch and one quarter in diameter were sealed at the lower ends and filled with water, into which was poured crushed fresh andesite intimately mixed with a small proportion of pulverized pyrite and chalcopyrite. These rock-filled tubes were then arranged in two sets of five, each set receiving a different vadose water from a small reservoir above, and being divided into two groups the larger of which was inclosed in an asbestos-lined box heated by electric lamps to 45° C. The tubes were so arranged and connected with each other, that each of the two vadose waters flowed separately into the heated and unheated groups, and then continuously through one tube and over and through the next neighboring one of the group, finally discharging through small glass and rubber ducts into a lower set of four glass tubes, two feet long and two inches in diameter, containing reducing agents, and representing the zone below ground water level.

These four lower tubes were grouped in pairs, standing erect like the upper ones. Two of them were filled with water into which was poured first coarse and then finer andesite, and then

half an inch of pure glass sand, this portion constituting a filter. Next came a thick layer of magnetite, one of olivine, one of chlorite, and finally a layer of all three minerals mixed together

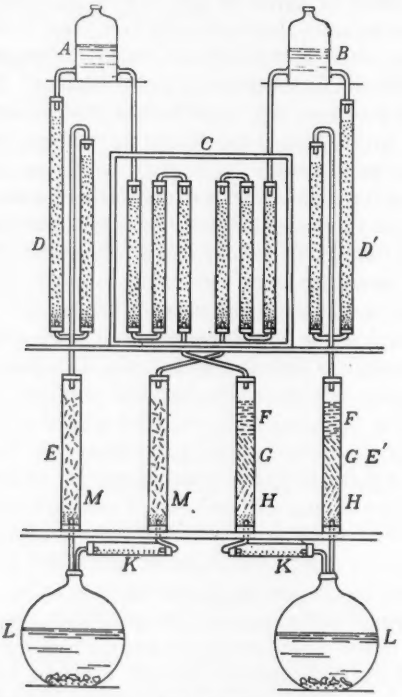

FIG. 37. APPARATUS USED IN THE SYNTHESIS OF PYRITE. *A*, solution of $HKCO_3$; *B*, solution of H_2SO_4 and $FeSO_4$; *C*, heating box; *DD′*, zone of oxidation, tubes of andesite with chalcopyrite and pyrite; *EE′*, zone of reduction; *F*, chlorite; *G*, olivine; *H*, magnetite; *K*, kaolin tube; *L*, carboy; *M*, andesite, asphalt, charcoal and iron.

with a little kaolinite added. In the other two tubes on top of the filter, was poured crushed andesite mixed with glass sand, asphalt, and sticks of charcoal weighted down with metallic iron.

Into each of these tubes a weighed piece of pyrite (two or three grammes) was inserted about midway in the filling.

These reducing tubes were then so connected with the upper groups that one unheated solution passed into a tube of mineral reducers while the other (the one enriched in acid potassium carbonate) passed into a tube of carbonaceous reducers; and the heated portion of the acid solution, which passed cold into the mineral reducers, was conducted into a tube of carbonaceous reducers, while the other heated solution passed into a tube of mineral reducers.

Each of these heated solutions discharged from the second zone into a horizontal glass tube about one foot long and two inches in diameter, which was half filled with slimed kaolin containing many weighed crystals of pyrite, and after passing through this tube discharged into a carboy containing all of the substances used in the tubes of the reducing zone. Into these carboys there also were added small quantities of humus acid which had been extracted from marsh soil.

The vadose solutions used were made up from tap water enriched in the one case by acid potassium carbonate, and in the other by sulphuric acid and ferrous sulphate, although both enrichments were so slight as to amount to scarcely more than traces.

Air was excluded from the system below the oxidizing zone by the careful sealing of the tops of the reducing tubes and of the carboys with sealing wax.

The aim of this arrangement was to give four conditions of oxidation of pyrite and chalcopyrite—two with each solution, first sunlight and room temperature, and second negligible artificial light and constant elevated temperature. It was also intended to give seven conditions of reduction and precipitation; namely: (1) circulation of unheated sulphuric solution through mineral reducers, (2) circulation of heated sulphuric solution through carbonaceous reducers, (3) circulation of heated sulphuric solution through kaolin with pyritic precipitation centers, (4) circulation of unheated carbonate solution through carbonaceous re-

ducers, (5) circulation of heated carbonate solution through mineral reducers, (6) circulation of heated carbonate solution through kaolin with pyritic precipitation centers, and lastly (7) stagnation of both solutions heated and unheated in the presence of all reducers including humus acid.

Results of the Experiment.—In starting the experiment much difficulty was experienced in making the tubes perfectly watertight at the lower ends, and in regulating the flow in and out of any given tube; but finally these difficulties were overcome and a fairly constant flow of one drop per minute secured. The heated carbonate system began running October 23, 1912, the hot and cold sulphuric acid systems November 6, 1912, and the cold carbonate system on November 10, 1912.

Near the last of November, 1912, a green slimy accumulation was observed to be forming around the grains of chalcopyrite and pyrite in the cold sulphuric tubes of the upper zone on the sides of the tubes nearest the adjacent window through which a strong sunlight came in the afternoons. Gradually more of this substance appeared in this and the other tubes exposed to sunlight, and finally it appeared in the heated sulphuric tubes immediately surrounding the sulphide particles, although it was relatively inconspicuous in these tubes. This was interpreted as indicating that the oxidation of the sulphides was in progress according to the reaction given above. About the first of April, 1913, when the experiment was dismantled this substance was analyzed and was found to be a sulphate of copper and iron.

About February 1, 1913, this same green sulphate was observed to be collecting on the filter of the carbonaceous reduction tube receiving the heated sulphuric solution, on the side facing the strong daylight. It was also noticed about the same time to be collecting in all higher portions of this and the other systems wherever strong daylight had access. This indicated that the solutions were transporting iron and some copper in the form of sulphates from the zone of solution down into the zone of reduction and precipitation. A subsequent analysis of the solutions from different parts of three of the systems in the upper and

lower zones showed that they were alkaline in reaction, and also carried aluminum sulphate. This probably means that the sulphuric acid liberated in the upper zone by the oxidation of the pyrite and chalcopyrite immediately reacted upon the silicates in the andesite to produce a basic aluminum sulphate.

In January, 1913, a black coating and discoloration was observed to be forming on and within the kaolin of the tube which took the discharge from the heated sulphuric system. About the same time or a week later the same phenomenon was observed in the other kaolin tube. When in April the apparatus was dismantled and these tubes were examined it was found that the black substance had formed moderately coherent modular masses with the kaolin, and that some of these had a core of minute cubic crystals of pyrite intergrown and cemented together to the complete exclusion of kaolin. Further examination showed that isolated cubes of pyrite occurred throughout the mass of kaolin, but that they were most abundant in or near to the black modules or films, which appeared to be dust-like precipitates of pyrite. In one or two cases it was found that the larger cubes of pyrite originally put into the tubes as crystallization centers had actually acted as was intended, and had been cemented together by aggregates of minute precipitated cubes. This artificial pyrite was roughly collected by washing and panning away the kaolin; and the pyritic concentrates were dried and weighed together with the natural pyrite originally inserted in the tubes. It was found that more than 1.11 gm. of pyrite had been precipitated in the kaolin tube receiving the heated sulphuric solutions, and that 0.66 gm. of pyrite had been precipitated in the other. The largest of these cubes measured 1 mm. in diameter.

Both carboys were then examined for pyrite and other sulphides. It was found that the carboy receiving the discharge of the first kaolin tube contained no sulphide of any kind, and that the other carboy contained 0.02 gm. of precipitated pyrite in three or four crystals, the largest being 3 mm. in diameter, which seemed to have formed in the kaolin.

A careful examination of the vertical reduction tubes failed to

reveal any pyrite or copper sulphide or precipitates of any other kind, the only changes produced by the circulation of the solutions being the oxidation of the ferrous oxide in some of the chlorite to a ferric condition, making a copper red coating on the surface of some of the fragments, the oxidation of most of the metallic iron in the carbonaceous tubes to Fe_2O_3, and the softening of the surfaces of some of the feldspar phenocrysts in the andesite.

It is an interesting fact that no free silicic acid, nor any free sulphuric acid, nor any crystals or other precipitate of aluminum sulphate, nor any precipitate of copper sulphide, were found anywhere in any of the systems, and that pyrite was not precipitated in any of the reduction tubes, but in the kaolin tubes and in the carboy receiving the discharge from the kaolin tube in which the lesser amount of pyrite was precipitated. During the early stages of the process the tubes and carboys were all filled with fresh oxidizing water which had not yet had an opportunity to part with its free oxygen. It may be, therefore, that the oxidation results obtained in the reduction zone were chiefly due to the original oxidized water, and only slightly to the subsequent circulation.

However, aluminum sulphate was found in the solutions, and copper sulphate probably would have been, had it been practicable to analyze them with sufficient care.

From an inspection of these results, it appears that the systems exposed to daylight and only room temperature, and discharging directly into the carboys without the intervention of kaolin tubes produced no sulphide precipitates, while both of the other systems precipitated pyrite but no copper sulphide. It is also evident that the character of the initial solution made no difference with the oxidation or reduction results unless it was that the sulphuric acid solution was the more active in acquiring and precipitating its load, the carbonate solution lagging behind in both processes. However, the quantity of pyrite precipitated and the promptness of its precipitation may have been greater in the case of the sulphuric solution because of the fact that it passed through car-

bonaceous reducers just before reaching the kaolin; but since no precipitation took place in the reduction tubes, it seems unlikely that they had any great influence. The significant thing seems to be the fact that the kaolin received the entire precipitation of pyrite.

Discussion of the Results.—In the earlier part of the paper it was suggested that pyrite was precipitated from an acid solution through the breaking up of the acid ferrous sulphate molecule through the catalytic action of previously crystallized pyrite. This reaction was surmised from the facts observed in the field and under the microscope in the study of a natural deposit, it being a matter of common knowledge that the underground waters from sulphide mines contain free sulphuric acid. However, it may be that these same waters, by the time they had percolated slowly through a great volume of feldspathic porphyry and were ready to precipitate pyrite, would have lost their free acid through its action upon the silicates of the rock, and would have become alkaline in reaction through the formation of basic aluminum sulphate. This possibility seems to be indicated by the results of the experiment, the solutions there used being acid at first, but becoming alkaline before they began depositing pyrite.

It is certain that the initial oxidation of the pyrite produced ferrous sulphate since the sunlight precipitated an iron-copper sulphate from the solutions in the oxidation tubes. It is also certain that free sulphuric acid was produced at the same time, for otherwise aluminum sulphate could not have been formed from the silicates of the andesite. Therefore the pyrite ultimately precipitated must have been derived from a sulphate solution of iron. The fact that this solution was basic may account for the fact that pyrite instead of marcasite was precipitated, yet it need not bar the possibility of the precipitating reaction being somewhat similar in character to the one originally suggested, the pyrite being derived from the breaking up of the ferrous sulphate molecule in the presence of crystals of pyrite, or in a reaction with kaolin.

Another possibility is that although some of the pyrite went

into solution as sulphate in an acid solution, the pyrite which was subsequently reprecipitated was taken into solution as pyrite in a basic sulphate solution, and carried in this form into an environment where free oxygen was absent, and slow circulation amid minute solid particles (of kaolin) made the precipitation and crystallization of the now insoluble pyrite easy. This idea though seemingly highly conjectural apparently has some support in experimental facts, since the same black precipitate noted on the surface of the white kaolin in the kaolin tube, and interpreted as incipient pyrite was also observed just within the outlet end of the glass tube delivering the solution to the kaolin tube. At this point the entering solution had not yet come in contact with the main mass of kaolin. This evidence, however, is inconclusive since it is possible that particles of kaolin suspended in the supernant fluid might have settled in the opening of this delivery tube and there have reacted with the entering solution to form the black precipitate.

Enough uncertainty still surrounds the details of these processes of solution and precipitation to make this experiment valuable only as a reconnaissance of the field studied, and the vital secrets remain to be unraveled by future research which the writer hopes to pursue. However, it has served one of its main purposes in demonstrating that pyrite can be precipitated from dilute cold water solutions under practically atmospheric pressure, and that the precipitation is favored or induced by aluminous material, or by fine slimes in a reducing environment.

ECONOMIC GEOLOGY OF THE BEREA SANDSTONE FORMATION OF NORTHERN OHIO.[1]

WILBUR GREELEY BURROUGHS.

The sandstones of the United States occur in all of the formations from pre-Cambrian to Tertiary.[2] Those of economic importance are widely distributed and small quarries supplying a local trade are numerous in many of the states. In several of these areas, the sandstone quarry industry has for a long time been operated on an extensive scale. The stone is used, not only locally, but is also shipped to distant points. Among the important regions, are the Triassic brownstone belt, extending from the Connecticut valley of Massachusetts, southwestward into North Carolina; the Medina and Potsdam of the Paleozoic era, much quarried in New York state; Devonian flagstones, extensively quarried at several places in New York state and Pennsylvania; and the Berea sandstone of the Mississippian period, quarried in Ohio. Numerous other Paleozoic sandstones of the central states are quarried, among which is the Potsdam, which covers a wide area in Michigan and Wisconsin. The Mesozoic and Tertiary strata of the western portions of the United States, also, are quarried in various places.

The sandstone is used as building-stone, flagstone, curbstone, paving-stone, ballast, break-water, etc. Special varieties are highly prized for the manufacture of grindstones, whetstones, oilstones, and pulpstones; and, after crushing, glass sand, polishing-sand, molding-sand, etc.

The leading sandstone-producing states, in 1910, were New York, which produced sandstone valued at $1,810,770; Penn-

[1] Published by permission of the Director of the Ohio State Geological Survey.

[2] ECONOMIC GEOLOGY, p. 117, Ries, Heinrich.

sylvania, $1,595,070; and Ohio, $1,402,131. The total value of the sandstone produced in the United States in 1910, was $7,930,019.[1]

BEREA SANDSTONE OF OHIO.

By reason of the importance of the Berea sandstone formation Ohio stands third among sandstone-producing states.

The Berea formation is so named from the fact that at first, it was extensively quarried at Berea, Cuyahoga County, northern Ohio. It is in great demand, partly because of its light color and its property of changing to a uniform buff tone on exposure to the atmosphere; and also because of its great resistance to weathering, the evenness of its texture, and the ease with which it is worked while containing the quarry-water. It has also the power of retaining inscriptions with the greatest fidelity, is extremely refractory, has great crushing strength, and can be made into a fine grade of grindstones.

The following data pertaining to the crushing strength of the Berea sandstone, and its uses in concrete, were furnished through the courtesy of Mr. H. E. Adams, general superintendent of the Ohio Quarries Company, Amherst, Ohio. The tests were made on Berea sandstone taken from the Ohio Company's quarries.

The following crushing strength test was made by Crowell and Murray, Cleveland, Ohio, January 13, 1913.

1 test	9,229	lbs.
1 test	8,846	"
1 test	10,308	"
1 test	9,739	"
1 test	6,883	"

Average 9,001 lbs. per sq. inch.

Uses of Berea Sandstone in Concrete.—Recent tests made by Crowell and Murray, Cleveland, Ohio, were made on 6 inch cubes.

Parts by volume: one part Lehigh cement, two parts standard sand, four parts two-inch Ohio Quarries Company sandstone.

[1] "Mineral Resources of the United States," 1910, p. 647.

The average per cube one month old, was 2,163; two months, 2,332; and three months, 2,435.

On 1½ inch stone, same proportion sand, cement, and stone, one month = 1,618; two months = 2,723; three months = 2,946.

In all cases these figures are the average for three tests.

The reason that the Berea sandstone is so highly prized as grindstone material, is that, due to its lack of cementing material, the sand grains remain sharp, even after continued use, thus making an excellent abrasive. The presence of much cement, on the other hand, nearly always causes a stone to glaze and lose its cutting power because the pores become filled with the cement. From the following analysis furnished by Mr. H. E. Adams, can be seen the composition of the best grade of Berea sandstone.

	Per Cent.
Silica	92.95
Alumina	3.14
Iron protoxide	1.22[1]
Lime	.13
Magnesia	.37
Alkalies	.65
Water (combined)	.80
Carbonic acid	.74
	100.00

This analysis was made by F. A. Emerton, chemist, Cleveland, Ohio.

METHODS OF QUARRYING.

The Berea sandstone formation, where quarried, is covered by glacial drift, seldom exceeding ten to fifteen feet. Beneath the drift comes a thin-bedded sandstone ten to twenty feet thick, and directly underlying this, the massive, commercial Berea sandstone or "Berea grit."

The stripping is done, in most instances, by hand, with the aid of horses, though at the Ohio Company's quarry a twenty-ton locomotive crane with a steam-shovel is used. When the work is done by hand, the following method is sometimes employed:

[1] There is no iron as pyrite present.

A pulley block is fastened to stakes driven in the ground at one side of the area to be removed. A tackle runs from a plow through the pulley block to the horizontal arm of a derrick on the opposite side of the section of land to the stakes; the tackle is fastened to the hoisting apparatus of the derrick machinery, which, on being started, pulls the plow across the tract of overburden to be removed. Another similar arrangement on the other side pulls the plow back to near its starting point.

About the only blasting done in the process of quarrying the Berea sandstone is in removing this overburden of thin-bedded sandstone. Infrequently, a small charge is necessary to split the massive commercial sandstone in the quarry, but this is not resorted to unless absolutely necessary, as it is likely to injure the stone.

In taking out the commercial Berea grit, the rock is cut across the bedding by a channeling machine. This makes a groove four inches at the top and two inches at the bottom, by six to ten feet deep. A machine is said to average about 250 running feet per day of nine hours. Only one groove is cut at a time. The blocks channeled are 6½ to 13 feet wide.

When the beds have been cut across, a number of holes are made with a drill in the top of the large sandstone block. This divides it up into a number of smaller blocks. In these drill holes are inserted two thin strips of iron, called "feathers," and between these "feathers" is driven an iron wedge or "plug," thus splitting the huge block into the desired number of lesser blocks. The sandstone is separated on the horizontal plane by use of a series of simple iron wedges driven in, splitting the rock along its bedding plane.

The stone is now ready for the derrick to lift it from the quarry. The maximum size of the sandstone blocks handled is 300 cubic feet. The usual size is 6 ft. × 6 ft. (or 5 ft. × 6 ft.), with a thickness of one to six feet. The sandstone blocks are transported on flat-cars to their final destination, or are made into grindstones, sawed into flagging, or transformed into fancy-dressed stone, for cornices, sills, etc. The imperfect rock is used for break-water, ballast, etc.

MANUFACTURE OF GRINDSTONES.

As has been stated, one of the important products of many of the quarries is grindstones. All sizes of grindstones are turned out, ranging from small ones, up to seven feet in diameter, with a thickness of fourteen inches.

In the manufacture of grindstones, the stone, sawed to nearly the desired thickness, is first cut by hand into a roughly circular shape and is then taken to the lathes. The lathe is passed through a small hole cut in the center of the stone with a pick for this purpose, and the stone is firmly clamped. The lathe is then set in motion, and as the stone rapidly revolves, a workman holds against the stone the end of an iron bar, called a "turning iron." The sides are thus smoothed and the stone ground to exactly the desired width. The stone is made circular by cutting a groove a short distance from the edge. If the groove is made too deep, the rim of stone may fly off with tremendous velocity, due to centrifugal force; therefore, the lathe is stopped after cutting the groove to a moderate depth and the rim of stone knocked off with a hammer. The rough edge that is left is smoothed by once more revolving the stone, with the turning bar placed against the edge. The rough surface where the stone was clamped to the lathe is smoothed by hand after the grindstone has otherwise been finished.

GREATEST ECONOMIC DEVELOPMENT OF BEREA SANDSTONE.

Thus far we have dealt with the Berea sandstone of northern Ohio as a whole. We will now consider that special district where the great bulk of the Berea grit is quarried and within whose boundaries are found all the geologic and economic problems with which the Berea sandstone of Ohio is associated.

The greatest economic development of the Berea sandstone formation occurs in Lorain County, Ohio, thirty to forty miles west of Cleveland. In the county itself the quarry industry is centered at South Amherst, six miles south of Lake Erie. Here, within an area of a trifle less than one square mile, are four of the principal quarries of the state, all of which are at present

being worked, as well as a number of smaller quarries, some of them now abandoned.

The amount of stone that has already been taken out can be seen from the dimensions of each of these four large quarry pits.

No. 6 quarry of the Cleveland Stone Company, opened over forty years ago, has a pit of rectangular shape, 2,632 feet in length, an average width of 460 feet, and a depth of from 100 to 175 feet.

The Ohio Quarries Company's pit is 1,500 by 175 feet, with a depth of 217 feet at its deepest point. It was opened during June, 1904. Since the above measurements were taken, the Ohio quarry has been enlarged somewhat.

The New Malone quarry is, on an average, 807 feet by 126 feet by 100 feet deep.

The Old Malone quarry is, on an average, 792 feet by 350 feet by 136 feet deep.

CHARACTERISTICS OF THE SANDSTONE DESIRABLE IN QUARRYING.

Of the massive sandstone quarried, there are two kinds—the buff sandstone which occurs in the upper portions of some of the quarries, and the blue sandstone which lies beneath the buff, or, when the buff is lacking, constitutes the entire product of the quarry. The blue is of a delicate bluish-gray color, and is harder than the buff. The reason for the difference in color and hardness of these two varieties of grit is as follows: In that part of the formation which, on account of its topographic position, has been thoroughly drained, the iron contained in the rock oxidized with the resulting buff color, while the portions not drained sufficiently have remained a grayish blue. The leaching and oxidation to which the buff sandstone has been subjected deprived it of a portion of its cementing material and also changed a large per cent. of the cementing iron carbonate to the more friable iron hydroxide, thus leaving the buff stone softer than the unoxidized blue.

Where not eroded away, the upper part of the Berea sandstone is composed of a series of somewhat coarse-grained, thinly-

bedded, gray sandstone, known locally as "shell," the beds being two to three inches thick. The surface of this series of beds is marked by well-defined glacial grooves and scratches, bearing in a southwest direction. This entire upper portion is generally ten to twenty feet thick.

Underlying these beds of shell sandstone, comes the massive sandstone with beds ranging from five to ten feet in thickness. These massive beds are made up of fine-grained, homogeneous stone.

Beneath the massive, commercial grit the formation changes into a hard, twisted, concretionary sandstone, called by the quarrymen "flint."

Underlying this concretionary rock at all the standstone quarries of the Amherst district is a bluish, finely-bedded, soft shale, different from the blue Bedford shale below the red Bedford, the Bedford shale being the formation coming next below the Berea sandstone formation. The shale beneath the sandstone of the Amherst quarries is believed to be of alluvial origin.[1]

The following is a section taken at the Ohio Quarry Company's quarry (Fig. 38), the deepest quarry in the region (217 feet deep):

"Shell" (sandy clay and thin-bedded sandstone showing on the sur-

[1] "The Unconformity between the Bedford and Berea Formations of Northern Ohio," by W. G. Burroughs, *Journal of Geology*, Vol. XIX., No. 7, pp. 655–660.

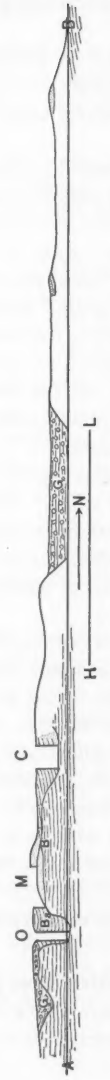

FIG. 38. Line $H-L$ = one mile on horizontal scale. Vertical exaggeration, 3.12. .....N = North. Line $A-B$ = elevation of 600 feet above sealevel. B = Bedford shale. BS = Berea sandstone. G = Glacial drift. O = Ohio quarry. M = Malone quarry. C = No. 6 quarry, Cleveland Stone Co.

face numerous glacial scratches bearing in a southwest direction), 16 feet.

Fine pattern, cross-bedded sandstone, called "spider rock," 10 feet.

Even-bedded sandstone, or "split" rock, 30 feet.

Coarser pattern, cross-bedded sandstone, called "cross-grain," 30 feet.

"Spider" rock, 10 feet.

"Split" rock, 10 feet.

"Cross-grain" rock, 10 to 15 feet.

Four-inch to five-inch beds alternating of "split" and "spider," 6 to 8 feet.

"Split" all the rest of the way down to the concretionary sandstone, under which is the blue "alluvial" shale, and then the Bedford shale.

On weathering, the Berea grit usually becomes a pleasant uniform buff color. Sometimes the walls of abandoned quarries and also buildings erected of this stone show banded and spotted discolorations, due to oxidation of irregularly distributed pyrite; but the walls of most quarries now being worked have weathered uniformly.

The principal supply of grindstone grit comes from the ordinary blue and buff sandstones. A special kind of sandstone for this purpose is that which is found in small patches, in the upper beds of the massive stone. These patches are scarce, but when found are sometimes twenty feet thick. This stone is a softer, more friable sandstone than the common grit. It is speckled with iron oxidized to limonite, rather loosely contained between the grains of quartz. It makes an excellent abrasive, and is highly prized for certain types of grindstones.

EFFECTS OF PETROGRAPHIC STRUCTURES ON COMMERCIAL EXPLOITATION.

The massive Berea grit is divided into three varieties according to the texture of the rock: "cross grain," "spider," and "split" are the names given to the stone at the quarries.

The cross grain is the result of cross-bedding of a somewhat coarse pattern. This coarse pattern is made by the shifting of the currents which deposited the sand over an extended period of time.

The spider is cross-bedding of a fine pattern, and represents more minute shifting of the currents. The surface of the spider beds is often ripple-marked. The ripple crests coincide with the knots of the web seen in vertical section.

The split is stone of even, uniform bedding and texture.

"Cutters."—There is one feature, fortunately rare in occurrence, in the structure of the commercial Berea grit which, where it occurs, ruins the value of the stone for any but ballast, breakwater, and similar purposes. This is what is known as "cutters." The stone breaks off along thin planes, sometimes almost invisible, which lie at a high angle with the bedding-planes of the sandstone. These planes are often filled with oxidized iron, and are then called "red cutters." Frequently there is apparently no foreign material in the cutter, or breaking-plane, with the result that it is scarcely discernible. These are known as "white cutters."

The writer advances the following explanation for the formation of cutters:

Along the bedding-planes of the sandstone has been deposited iron, which is now oxidized. This oxidized iron brings to view what has transpired. On close examination of the red cutters, it is seen that a displacement has occurred. The bedding-planes on the hanging-wall side of the cutter have been thrust up a fraction of an inch relatively to the bedding-planes on the foot-wall. It was this minute faulting that formed the cutters, which are in reality miniature fault planes.

The folded structure of the region bears out the suggestion made by the broken bedding-planes. Later circulating waters deposited iron in these fault or cutter planes, which on oxidizing formed the present red cutters; while the white cutters had no iron deposited in them. The cutters are not found at any uniform horizon, but in general they may be said to occur near the crest of minor anticlines.

GEOLOGY OF THE REGION.

(*a*) *The Bedford and Berea Formations.*—The formations of the Amherst region belong to the Waverly Group of the Mississippian. The only formations outcropping in the immediate vicinity of the South Amherst quarries are the Bedford shale and the Berea sandstone. The former is an argillaceous shale, the lower portion for five to ten feet being soft and bluish gray in color, very finely bedded, and having interbedded in it a few hard, limy layers one to one and a half inches thick of a gray color; the upper portion of the Bedford formation is of a marked red or chocolate color. Its properties otherwise remain similar to the dark, bluish gray shale below, save that no limy layers occur. There is usually a thin sandstone layer at the contact of the red and blue Bedford. As one goes westward this sandstone layer thickens, until west of Berlin Heights it is ten to twenty feet in total thickness, being made up of sandstone beds one to six inches thick.

The red portion of the Bedford formation aids one greatly in searching for the Berea sandstone just above.

The Bedford is underlain by the Cleveland shale, a black, thin-bedded shale, which comes to the surface north of the Amherst district, and continues to Lake Erie.

(*b*) *The Bedford-Berea Unconformity.*[1]—As one goes along Beaver Creek, or Chance Creek, streams to the east and west of the quarries, occasionally he will find the high banks covered by a mass of Berea sandstone talus. This débris came from a local occurrence of sandstone in place at the top of the bank, extending for 50 to 100 feet on the horizontal and flanked on either side by red Bedford shale. In places the sandstone is in thin beds two to three inches thick; at other places in massive beds three to four feet thick. The deposits range from ten to fifty feet in total thickness. Their long axis runs in a general east-west direction.

[1] "The Unconformity between the Bedford and Berea Formations of Northern Ohio," by W. G. Burroughs, *Journal of Geology*, Vol. XIX., No. 7, pp. 655–660.

Drill records also show the unevenness of the surface of the Bedford shale of former ages (Fig. 38). Within 100 feet to the south of the deepest part of the Ohio quarry where 217 feet of Berea sandstone has been penetrated and starting on the same level as the top of the quarry, the drill passed through sixty feet of glacial drift and then struck Bedford shale without encountering any sandstone, and yet the strata were dipping in that direction at an angle of 6°. One bank of the channel in the erosion plane of the Bedford formation was thus located; although the quarry is 175 feet wide, both of its walls are still composed of solid sandstone.

By drill and well records the writer has traced this sand-filled channel in the eroded horizon of the Bedford shale for three and one half miles to the southwestward where it outcrops on the banks of Chance Creek. The deposit diminished in size, being fifty feet wide and fifteen feet thick. This indicates that the stream in whose channel the sand was deposited flowed from the southwest toward the east.

Numerous other borings, as well as all the principal quarries (Fig. 38), tell the same story—a rough, broken topography of the Bedford shale previous to deposition of the sand from which the Berea formation originated. The sand filling these channels in the surface of the Bedford shale gave rise to the sandstone bodies found along the streams of present times and by the drill. A false impression of the thickness of the Berea formation is thus apt to be made, and where a few borings might appear to show a valuable and thick deposit of sandstone, there may in reality be but a small body of little commercial importance.

Regarding the source of the sand forming the Berea formation, the Ohio Geological Survey Report, Vol. II., p. 89, states that the Berea sandstone in Michigan, where it apparently is represented by the Napoleon sandstone, attains a thickness of 107 feet. Going east and south from Lorain County the arenaceous material progressively diminishes until in Kentucky and Tennessee scarcely any sandstone, properly speaking, is found in this geological series; in eastern Ohio and western Pennsylvania argillaceous

material, derived from an eastern source, enters into the composition of the Berea beds.

From these facts it would seem that this arenaceous material which went to make up the Berea grit was transported from land lying to the northwest.

(*c*) *Structure of the Region.*—The region has been folded into small anticlines and synclines; but these folds are on the whole very gentle, and have no important bearing whatsoever on the economic geology of the region.

(*d*) *Pre-glacial Erosion of the Berea Formation.*—When the deposition of the Berea sandstone first commenced in this region its development was local and patchy, occurring in the valleys of the eroded Bedford shale, thus making the bottom of the Berea irregular, but deposition continued long enough to fill completely the Bedford valleys and make the sandstone more or less continuous over the area. The waters from which the sand was deposited having withdrawn, erosion took place, dissecting the Berea formation.

Evidence of this pre-glacial erosion is shown, for example, by borings made one mile north of No. 6 quarry of the Cleveland Stone Company at South Amherst. The drill went down 100 feet and found nothing but a mass of glacial drift throughout the entire distance. The boulders encountered were of Berea sandstone intermixed with clay. For a half mile east and west, and one mile north and south, the same mixture of sandstone and clay was found. This depression in the Berea was carved out before the coming of the glaciers which subsequently filled it with the boulders and clay, for within one mile both north and south of this eroded surface of the Berea occur quarries in solid Berea sandstone 60 to 125 feet thick with strata dipping at slight angles to the southeast and northwest, the dips being too slight to carry the sandstone to any considerable depth at the depression just mentioned. The lack of sandstone is therefore without doubt due to pre-glacial erosion. This same irregularity takes place many times throughout the district. A notable break in the sandstone occurs a few hundred yards west of the Ohio

quarry, and can be traced by borings in its course to the northwest. This channel is 200 to 300 feet wide, evidently being the valley of a river which flowed through the Berea sandstone before glacial times.

CONCLUSION.

The economic importance of the Berea sandstone formation is affected by several geologic factors:

1. The formation is of greatest value where it fills a channel eroded in the Bedford shale. This can only be ascertained by drilling.

2. In certain places small fracture planes, known as cutters, occur in the Berea grit. Along these planes a minute amount of faulting has taken place, due to the dynamic forces acting in the region. Stone of this type is worthless save for ballast, breakwater, and similar purposes.

3. Extensive erosion suffered by the Berea prior to the glacial period makes it impossible to know, but by drilling, whether sandstone lies beneath, for the channels in the Berea were filled with glacial drift. In some instances the absence of sandstone may be due to lack of deposition, the sands having been deposited only in the pre-Berean valleys.

GOLD DEPOSITS OF PORCUPINE DISTRICT, ONTARIO.

REGINALD E. HORE.

In the fall of 1909 important discoveries of gold were made in the Porcupine district, Ontario, about 100 miles northwest of Cobalt and 360 miles north of Toronto. Development work has proved some of the deposits to be large and of very profitable grade. Two mines, Dome and Hollinger, are now producing on a large scale and several are contributing smaller amounts. About $2,000,000 was produced in 1912 and a much larger output is expected for 1913.

The ore is native gold in pyritic quartz. The quartz occurs[1] as (1) single fissure fillings or veins; (2) a series of fissure fillings running nearly parallel—vein system; (3) quartz-ferrodolomite lodes in which quartz veins penetrate bands of ferrodolomite or iron-calcium-magnesium carbonate; (4) quartz masses of irregular form, chimneys, kidneys, etc., and some more or less parallel, thick, lenticular masses.

The quartz is partly coarse-grained, but much of it is very fine-grained and has evidently been crushed. Granulation is indicated by the appearance of thin sections and strain phenomena are common. Some of the quartz shows a ribboned structure with banding in direction of the strike of the veins.

The gold is mostly in fine particles, but much also is in coarse grains and in the ore is frequently visible to the naked eye. Most of the visible gold is in parts of the quartz near the wall rock or masses of enclosed rock and assays indicate a similar distribution for the invisible gold. Pyrite is almost always present in both quartz and wall rock and is more abundant in the latter. The gold is intimately associated with the pyrite and sometimes intergrown with it. Much of the visible gold near pyrite, however,

[1] Descriptions of four typical deposits were given in *Canadian Mining Journal*, Nov. 1, 1910, pp. 649-656.

is not actually in contact with it. There is some calcite in the ore, but it is not present in large quantity. Tourmaline, generally in aggregates of small crystals, is often found in the quartz. Scheelite has been found in a few veins.

Microscopic Characteristics of the Gold Ore.—The examination of numerous thin sections shows that there are certain differences in the ore from the several deposits, but these seem to be of a minor nature and the following description of gold-quartz from the Dome Mine may be taken as fairly typical of the Porcupine mines.

The quartz is not uniform in grain and one may distinguish readily between part that is coarse and part that is fine. The coarser grains are commonly 0.5 mm. to 1.0 mm. in diameter, while the finer are about 0.05 mm. The coarse has numerous small cavities partially filled with liquid inclusions, and shows marked strain shadows; the fine has fewer inclusions and strain effects are not so marked. Fine-grained quartz forms streaks running through the coarse-grained. In some cases two coarse grains are separated by a row of fine grains, which have apparently been derived from the former by crushing. In one specimen an area, 1.0 mm. in diameter, of fine-grained quartz encloses an isolated coarse grain 0.2×0.4 mm. in diameter. The finely crystalline has apparently been formed largely by granulation of the larger grains. The small particles are firmly cemented together and there was evidently some solution and recrystallization though the cement is not distinguishable under the microscope.

In the fine-grained portions there is a notable absence of large fluid inclusions and evidently some such fluid was able to move among the fine quartz particles. The presence of fluid inclusions in the quartz indicates that it was hot when solidifying. The granulation of the quartz indicates that it was comparatively cold when crushed.

MODES OF OCCURRENCE OF GOLD IN DOME MINE QUARTZ.

1. *Gold completely enclosed in one grain of coarsely crystalline quartz, e. g.*, one grain of quartz 0.5×0.8 mm. in the plane of

the section completely encloses three isolated grains of gold. The small size of these gold grains makes it appear unlikely that they were not completely enveloped in the quartz, though there is a possibility that they were not. Another quartz grain 1.0 mm. in diameter enclosed three ragged grains of gold about 0.04 mm. in diameter and several gold particles 0.01 mm. or less in diameter.

2. *Gold in spaces between grains of coarsely crystalline quartz, e. g.,* one U-shaped area of gold 2 mm. long and 0.02 to 0.06 mm. wide forms a ragged band between coarse quartz grains. It forms a border for two thirds the periphery of one quartz grain—hence the shape. In several sections there is gold showing similar relation to coarse quartz grains.

3. *Gold in crystals and grains of pyrite, e. g.,* one area of pyrite 0.5 mm. × 1.0 mm. encloses several irregular patches of gold, most of which are less than 0.1 mm. in diameter. Four of these gold grains are completely within the pyrite, while a much greater number are partially enclosed by the pyrite and partially by quartz. A second and rectangular area of pyrite 0.5 mm. × 0.1 mm. has along its middle portion five areas of gold. The string of gold particles continues from either end of the pyrite into clear quartz. Another specimen shows an area of gold 0.6 × 0.1 mm., which is four fifths enclosed by pyrite, while the end projects into colorless minerals. The part of the gold not enclosed by pyrite is on one side in contact with calcite and on the other with a grain of quartz.

4. *Gold Grains in Calcite, Completely or Partially Enclosed.*—A twinned individual of calcite 1 mm. × 0.5 mm. is enclosed chiefly by fine-grained quartz, and one end is in contact with an area of pyrite 1 mm. in diameter. Around the edge of the calcite, and in immediate contact with it, are nine distinct particles of gold. Within the calcite, and arranged in a string roughly following a cleavage direction, are six grains of gold 0.02 to 0.03 mm. in diameter.

A second specimen shows an area of calcite 0.1 mm. × 1.0 mm. enclosing a number of small gold grains. This calcite is partially enclosed in fine quartz, but also fills a fracture in one large quartz grain. This same specimen shows gold in quartz with no calcite in contact.

Another specimen shows a grain of calcite 0.5 mm. in diameter, which wholly or partially enclosed twenty ragged grains of gold. The gold is irregularly scattered through the calcite, but is mostly at the edges. The calcite is surrounded by fine quartz 0.05 mm. in diameter.

5. *Gold among grains of finely crystalline quartz, e. g.,* one very irregular area of gold, 1 mm. long and varying in width from 0.02 to 0.1 mm. is almost completely enclosed by fine-grained quartz, whose particles average 0.03 mm. in diameter. That part of the gold not enclosed by quartz is in contact with calcite. It is noteworthy that most sections showing gold show also fine (probably granulated) quartz, and small amounts of calcite.

Characteristics of the Wall Rocks.—The gold quartz occurs in rocks of the Keewatin and Huronian series. The Keewatin is composed largely of igneous with some sedimentary rocks. The Huronian is largely sedimentary. Most of the deposits are in altered quartz porphyry, others in more basic rocks—porphyrites, basalts, etc.—conveniently called greenstones. Some are in conglomerate and greywacke—slate.

Mr. A. G. Burrows, who has mapped the area for the Ontario Bureau of Mines, gives the following succession of formations for the district:

"*Pleistocene*—Post Glacial—Stratified clay, sand and peat.
Glacial—Boulder clay.

Pre-Cambrian. *Later Intrusives*—Quartz-diabase, olivine-diabase, etc.

Igneous contact.

Cobalt Series—Conglomerate.

Unconformity.

Temiskaming Series—Conglomerate, greywacke, quartzite, slate or delicately banded greywacke.

Unconformity.

Laurentian—A complex of granites older than the Cobalt series. It intrudes the Keewatin, but its

relationship to the Temiskaming is not definitely known; it may be in part older and in part younger than the Temiskaming series.

Igneous contact.

Keewatin—The series consists chiefly of basic to acid volcanics, much decomposed, and generally schistose; amygdaloid basalts, serpentine, diabase, quartz or feldspar porphyry, felsite, iron formation, rusty weathering carbonates and other rocks have been recognized."

The Cobalt and Temiskaming series referred to by Mr. Burrows are divisions of the Huronian corresponding to those made by Dr. W. G. Miller at Cobalt and by Mr. Robert Harvie[1] in the area east of Lake Temiskaming. Mr. Harvie calls the lower sediments "the Fabre series."

The gold is found in quartz occurring in the several types of rock comprising the Keewatin and Temiskaming series, but it is noteworthy that the wall rocks of all the ore bodies, while probably originally quite different, have remarkably similar composition. This similarity is due to alteration, by which the minerals have been replaced by sericite, carbonates, quartz and chlorite. The light-colored wall rocks[2] are largely made up of the first three minerals. In the darker ones there is much chlorite. Pyrite occurs abundantly and is commonly well crystallized. The wall rocks are commonly not highly auriferous except where penetrated by quartz stringers. Where thus silicified, the rocks sometimes contain payable quantities of gold.

Origin of the Deposits.—We have in the Porcupine district pyritic gold quartz deposits enclosed in rocks characterized by an abundance of ferrodolomite, sericite and pyrite.

[1] "Geology of a Portion of Fabre Township," Quebec Mines Branch, 1911.

[2] Microscopic description of several of the rocks is given by C. W. Knight and A. G. Burrows in the Bureau of Mines report, 1911. Mr. John Stansfield described rocks and ores from Vipond Mine in *Canadian Mining Journal*, Feb. 15, 1911. The wall rocks of Dome, Hollinger and Rea mines were described by the writer in *Trans. Can. Min. Inst.*, 1911, pp. 173–178.

The occurrence of these minerals in all the deposits is doubtless due to common origin and any hypothesis as to the origin of the gold must also satisfactorily explain the conditions of formation of these associated minerals. The hypothesis outlined[1] in the following paragraphs helps to correlate the observed facts. The nature of the ore and the wall rocks suggests that the gold was introduced into the fissures along with the chief constituents of the minerals mentioned. The solution[2] which contained the gold probably contained also in some form iron, sulphur, silica, potassium and carbon dioxide. From the solution practically all the potassium and carbon dioxide escaped into the wall rocks and aided in the formation of sericite and ferrodolomite. Part of the iron and sulphur also escaped into the wall rocks and there formed pyrite crystals and contributed iron to the formation of ferrodolomite. Part of the iron and sulphur and nearly all of the gold and silica was deposited in the fissures themselves. It appears that the walls were more readily penetrated by some constituents than by the others,[3] and in this way much of the CO_2, K, S and Fe escaped. In proportion as these constituents escaped the solubility of the gold in the remaining solution would be decreased and the deposition therefore aided by removal of solvent as well as by lowering of temperature. The pyrite first formed in the veins was comparatively poorly crystallized and was probably formed quickly. The pyrite in the wall rocks, and some pyrite in the veins that is probably of secondary origin, is in well-formed crystals and evidently formed slower or at least under some more favorable conditions than did the original auriferous pyrite of the quartz veins. The gold and pyrite were not evenly distributed originally. Evidently in the first crystallization they tended to segregate here and there, and the especially favorable place for deposition was near the walls or around masses of enclosed rock.

[1] The origin of the deposits is discussed more fully in a paper presented at Toronto meeting of Can. Min. Inst., 1912. Vol. XV.

[2] For discussion of transport of gold in solutions containing such constituents see "Macaren Gold," pp. 105–107.

[3] Cf. Lindgren, "Characteristic Features of California Gold Quartz Veins," *Bull. Geol. Soc. Am.*, 1895.

After the filling of the fissures with quartz, gold and pyrite, the veins were shattered and the quartz granules strained or crushed. In the crushed zones a secondary set of minerals, including sericite, chlorite, calcite, ferrodolomite and pyrite and some gold, were deposited. These probably originated in the vein and wall rocks. The gold thus formed is in coarse grains which probably grew by slow accretion of small particles by a process continued over a long period. It is probable that this coarse gold grew at the expense of the fine gold contained in the quartz in its immediate neighborhood, thus leaving much very low grade quartz in the vicinity of the spectacular specimens. The coarse gold, to which a secondary origin is here attributed, while showy, is usually quite subordinate in amount to the fine gold, much of which may well be still in the form in which it was first deposited with the pyrite and quartz. Some fine gold, however, is probably secondary, and there are presumably cases in which the amount of secondary gold is greater than the amount of primary.

There is nothing to indicate that the character of the deposits has to any considerable degree been changed since the glaciers cleaned away the surface rocks, and there is therefore no reason for believing that the ore will show any appreciable dependence on the present surface. The secondary changes which have taken place are not surface alterations.

DISCUSSION

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of more formal papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, Sheffield Scientific School of Yale University, New Haven, Conn. The full name of the author should be attached to all communications.

FIELD AND OFFICE METHODS IN THE PREPARATION OF GEOLOGIC REPORTS.

A MODIFICATION OF THE WALCOTT METHOD OF MEASURING STRATIGRAPHIC SECTIONS.

Sir: For many years Dr. C. D. Walcott has used a rod and clinometer for measuring sections of inclined strata.[1] The method is very simple and easily practiced. An ordinary clinometer compass is fastened securely to a rod of such length that the sight is on a level with the eye when the rod is standing upright on the ground. To quote from the original description:

"The strata, in the section to be measured, were inclined to the east 40°. Placing the lower end of the rod at the base of the section, I inclined the rod towards the edges of, and at a right angle to, the line of the dip of the strata, which was indicated by the needle of the clinometer standing at 40°. Then, looking through the compass sights, the point where the line of sight touched the ground was marked as the next station for the rod, and on this station the base of the rod was placed for the second sight, which was made exactly as in the first instance, and so on to the end of the section. Frequent trials were made, at the exposed outcrops, to determine the angle of dip of the strata, so that the rod might be held at a right angle to it."

While using this method in the field the past few years, I have found that certain modifications tend to make it more accurate

[1] A brief description of this method is published in the *Proceedings of the U. S. National Museum* for 1888, pp. 447–8.

and convenient. In fact, it is the most accurate and generally satisfactory method which I have found practicable in ordinary field work.

For the longer rod suggested by Doctor Walcott, I have substituted one about 5 feet 1 inch high, for the purpose of bringing the compass sight at a height of exactly 5 feet above the base of the rod. This has two advantages: five feet is a convenient unit for making mental calculations of the thickness of a great series of beds; it is also much more convenient to use when the geologist is ascending a steep slope in which the beds are nearly horizontal. A trial will readily demonstrate that it requires severe stretching to look through the sights on a rod held in front of one on such a slope, unless the rod is considerably shorter than

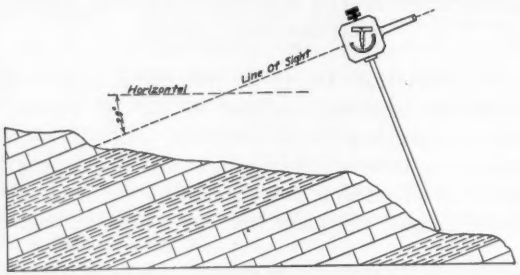

FIG. 39. Diagram illustrating the measurement of strata by means of a spirit level clinometer and sighting arm attached to a five-foot rod.

the man. In addition, I find it advisable to graduate the rod by cutting rings around it at intervals of 1 foot or ½ foot. This makes it easy to estimate the thicknesses of beds less than 5 feet thick.

By using a Brunton compass, or some other instrument in which the free swinging clinometer needle is replaced by an adjustable spirit level, the geologist is relieved of the necessity of watching the swinging needle to see that it stays at the proper figure. All that is necessary is to set the indicator which is attached to the spirit-level at a figure corresponding to the dip

angle, and then lean the rod until the bubble, as seen in the mirror, appears in the center of its tube. The line of sight will then be parallel to the dip. In order to hold firmly in the most convenient position the swinging cover which contains the mirror, a little metal arm may easily be provided as shown in the diagram.

On account of the form of the Brunton compass, it is necessary to use an attachment by which it may be firmly fixed upon the rod. For this purpose I use a brass ferrule large enough to take the end of a stick the size of a stout walking cane. To the side of this ferrule is soldered a clamp with a double milled set-screw. This not only holds the compass firmly in place, but holds the sight of the compass at exactly right angles to the axis of the rod.

This simple apparatus, consisting of the Brunton compass and the ferrule clamp, goes readily in the pocket; and the necessary stick can be cut wherever convenient. It saves time, however, and in barren regions it is necessary, to start out with a good staff and use it indefinitely.

FIG. 40. Clamp and ferrule for attaching Brunton compass or other clinometer to five-foot rod.

By taking frequent readings of the dip angle, sections can be measured as accurately as is desirable, considering the wavy character of most bedding planes and the local variations in the thickness of beds. The method has the great advantage of permitting the geologist to make frequent offsets along the strike from outcrop to outcrop in order to keep always upon the best exposures. Moreover, it gives the results directly and instantly for each bed, without any more laborious calculations than easy mental arith-

metic. If the geologist has an assistant, as he ought to have in work of this kind, the latter should handle the instrument and devote his whole attention to the measurements, merely giving the geologist the result, as the study of each bed is completed. By this arrangement the geologist himself is left entirely free to study the character of the rocks, take specimens, write notes, examine contacts or collect fossils, without being distracted by the necessity of paying attention to the mechanical process of measuring.

ELIOT BLACKWELDER.

TABLES SHOWING APPARENT DIP OF STRUCTURE PLANES, IN ANY VERTICAL SECTION.

Sir: During the field season of 1911, the writer had the pleasure of being associated with Mr. J. M. Boutwell, on a geological survey of the Pilares District, at Nacozari, Mexico, for the Moctezuma Copper Company. Towards the close of this work, several geologic sections were run, where precision was of the utmost importance. Consequently, the need was felt for tables showing the apparent dip of structure planes, whose strike was at oblique angles to the plane of the section.

APPARENT DIPS. TABLE I.

Actual Dip.	Angle Between Direction of "Dip" and Line of Section.								
	10°	20°	30°	40°	50°	60°	70°	80°	90°
10°	10°	9½°	8½°	7½°	6½°	5°	3½°	2°	0°
20°	20°	19°	17½°	15½°	13°	10½°	7°	3½°	0°
30°	29½°	28½°	26½°	24°	20½°	16°	11°	5½°	0°
40°	39½°	38°	36°	32½°	28½°	23°	16°	8½°	0°
50°	49½°	48°	46°	42½°	37½°	31°	22°	11½°	0°
60°	59½°	58½°	56½°	53°	48°	41°	30½°	17°	0°
65°	64½°	63½°	61½°	58½°	54°	47°	36½°	20½°	0°
70°	70°	69°	67°	64½°	60½	54°	43°	25½°	0°
75°	75°	74°	73°	71°	67½°	62°	52°	33°	0°
80°	80°	79½°	78½°	77°	74½°	70½°	63°	44½°	0°
85°	85°	84½°	84°	83½°	82°	80°	75½°	63°	0°
90°	90°	90°	90°	90°	90°	90°	90°	90°	—

Accordingly, at Mr. Boutwell's suggestion, the writer prepared tables, which were tested in the construction of these sections,

and which proved so useful in getting accurate results, that they are here given, with the hope that they may prove of similar service to others. These tables, which are self explanatory, are based on the formula for the slope of the line of intersection of two planes, one of which is vertical. The development of this formula follows. (See Fig. 41.)

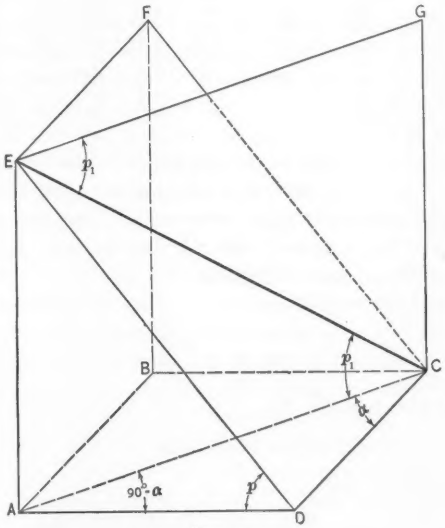

FIG. 41.

Given: (*a*) The rectangular inclined plane *EFCD* whose strike is *CD* and actual dip is "*p*."

(*b*) The plane of the vertical section *AEGC*, intersecting the inclined plane along the line *EC*.

To find: "p_1," the apparent dip of the inclined plane in the plane of the section *AEGC*.

Let (*a*) *ABCD* be a rectangular horizontal plane through *CD*, intersecting the plane of the section along the line *AC*.

APPARENT DIPS. TABLE II.

Actual Dip.	Angle Between Line of Strike and Line of Section.								
	10°	20°	30°	40°	50°	60°	70°	80°	90°
10°	2°	3½°	5°	6½°	7½°	8½°	9½°	10°	10°
20°	3½°	7°	10½°	13°	15½°	17½°	19°	20°	20°
30°	5½°	11°	16°	20½°	24°	26½°	28½°	29½°	30°
40°	8½°	16°	23°.	28½°	32½°	36°	38°	39½°	40°
50°	11½°	22°	31°	37½°	42½°	46°	48°	49½°	50°
60°	17°	30½°	41°	48°	53°	56½°	58½°	59½°	60°
65°	20½°	36½°	47°	54°	58½°	61½°	63½°	64½°	65°
70°	25½°	43°	54°	60½°	64½°	67°	69°	70°	70°
75°	33°	52°	62°	67½°	71°	73°	74°	75°	75°
80°	44½°	63°	70½°	74½°	77°	78½°	79½°	80°	80°
85°	63°	75½°	80°	82°	83½°	84°	84½°	85°	85°
90°	90°	90°	90°	90°	90°	90°	90°	90°	90°

Let (b) ∞ = the angle between AC (*the line of the section*) and CD (*the line of strike*).

Whence $90° - \infty$ = the angle between AC (*the line of the section*) and AD the *direction of dip*.

Now the angle ACE = angle $CEG = p_1$
and in the right $\triangle EAC$

$$\tan p_1 = \frac{EA}{AC} \qquad (1)$$

In the right $\triangle EAD$

$$EA = AD \tan p. \qquad (2)$$

In the right $\triangle ADC$

$$AD = AC \cos (90° - \infty). \qquad (3)$$

Substituting in equation (2) for the value of AD from equation (3)

$$EA = AC \cos (90° - \infty) \tan p. \qquad (4)$$

Substituting in equation (1) for the value of EA from equation (4)

$$\tan p_1 = \frac{AC}{AC} \cos (90° - \infty) \tan p, \qquad (5)$$

whence

$$\tan p_1 = \tan p \cos (90° - \infty) \qquad (6)$$

from which Table I. was derived or

$$\tan p_1 = \tan p \sin \infty \qquad (7)$$

from which Table II. was derived.

HENRY MOSIER.[1]

A SPECIAL PLANE-TABLE FOR WORK ON A LARGE-SCALE BASE-MAP.

Sir: In the season of 1912, the writer was employed by the Topographic and Geologic Survey Commission of Pennsylvania to make a general report for a bulletin on the Broad-Top coalfield. The results desired were of such detail that a field-scale of 500 feet to one inch was adopted. In doing the work on this scale, a special plane-table was designed that gave eminent satisfaction and a description of its pattern and use may prove of value to geologists engaged in constructing maps under similar conditions.

It is not to be assumed that this method would in any manner substitute for the ordinary plane-table as used by topographers or by the geologists of the U. S. Geological Survey who are making maps over extensive areas of the public domain. But in a field where there are a large number of operating mines and where the geologist can secure a base-map that gives the locations of creeks, roads, houses, etc., all on one large map, or where he can compile such a map, then the scheme as outlined will be found very satisfactory.

The base-map used by the writer had been compiled from township maps showing property lines, roads, towns, drainage, etc., together with all coal mines and outlines of underground workings as made by a civil engineer. In addition to this, all maps below the surface were in possession, being on a scale of 100 feet to one inch; these were used when necessary for the details of structural features, but were apart from the general base-map.

In bringing about the uniform reduction of the various mine maps and assembling the material on one large, connected map, economy of expenses and time had demanded that it be on tracing

[1] Chief Geologist, Moctezuma Copper Company. Paper presented at the Morenci Session of the Phelps-Dodge Geologic Conference.

cloth. The Broad-Top field is about forty-five square miles in area excluding the outer border of Pottsville rocks, so that the map of the entire field was separated in two parts. Each of these was more than four feet wide and considerably more than that in length, so that it was at once apparent that in order to facilitate the use of the material in the field, the map would have to be divided into a large number of small pieces or some method devised for handling the large portions in the field. With a large, unmounted map in the field one could not write on it conveniently at any time and dare not attempt to unfold or unroll it on windy

FIG. 42. The board as it looks when set up in the field.

days, much less attempt to use any modern methods involving intersections, vertical angles, etc. Consequently a plane-table, or roller-board, was brought into play as described in the following paragraphs.

The board fits onto an ordinary tripod, it being only necessary to remove the metal disk from the under side of any standard plane-table, or traverse-board, and attach it underneath the central portion of the special board, boring out a hole of sufficient depth

to take the tripod plug that screws up and down by the adjusting nut that tightens and loosens the board. In this connection, a piece of bristol board, or light wood, cut the same size as the metal disk and placed under it will give room for the plug-head space in the thin wood that must also hold imbedded the points of screws that fasten the disk to the under side of the board.

In the present case the board was neatly manufactured by Mr. Harry Gibbony, of Everett, Pa., at a cost of about four dollars. Mr. Gibbony operates a planing-mill and would no doubt undertake to make a board along similar pattern for anyone who might desire it. It is made of light maple and in order to combine maximum strength with minimum lightness, the flat portion is made three-ply; that is, veneered with three very thin pieces with the grain of the wood at different angles. The length of the board can of course be made to suit the circumstances but the longer it is not to have excessive weight, the more adaptable it is for maps of various lengths. It should be about ten inches in width. Lengthwise with the board are placed two, small, light maple rollers. One end of the map can be fastened to one of these rollers with thumb tacks and rolled onto it; then the other end is fastened to the other roller so that it will roll back and forth between the two thus exposing all portions of the map when desired. The longest dimension of the map plays between the two rollers and its width is, of course, less than the length of the board. For instance, a board four feet long will take a map of slightly less width and of indefinite length. In case the geologist should wish to do sketching along a line of railway where a long roll, possibly a blue-print, is the only base to be had, a very light, short, roller-board could be made so as to take a long length of the road.

The two rollers as shown in the cut presented herewith are attached to the two end braces below the plane of the board, so that the map draws flat on the surface; in addition, two rubber bands are placed around the ends of the map on the board to hold it closely down. It is necessary to be provided with a cover in case of rain and to combine its use with that of a carrying case in going to and from work. The cloth manufactured for buggy

tops or any heavy oil-cloth is sufficient for his purpose. The case is left open at the end to receive the board and contains a flap and buckle to inclose it. It should also have an adjustable leather shoulder strap fastened at two points along the edge. The board used by the writer is four feet ten inches long and eleven inches wide including the rollers; it weighs about six pounds.

In view of the recent excellent articles that have appeared in ECONOMIC GEOLOGY on the use of the plane-table in geologic mapping, it is useless to here attempt a discussion of that particular subject. It is sufficient to say that all the methods used in ordinary plane-table work can be used in the same manner with the roller-board. The roller-board has the advantage of permitting longer intersections, however, in any direction. If the line of intersection lies across the narrow way of the board, or is a long line diagonal to it, it is only necessary to draw the line on the flat surface, then roll the map in the opposite direction until the line can be extended. North-south or east-west lines are drawn on the map for the purpose of orienting it by placing the edge of the compass along any one of the lines and turning the table until it is properly placed with respect to points of the compass. A heavy telescopic alidade could not be used conveniently on such a long, light board but one of the small patters such as the B. and L. Gale Alidade could be used. As an open sight alidade the hand Gurley or "Forester's Compass" with the two hinged standards and adjustable for declination is satisfactory. This compass was mentioned by Dr. Ransome for use with the ordinary plane-table and from his article in this journal, the writer caught the idea of using it. The K. and E. "Geologist's Compass" is, of course, similar. The objection may be raised by some that the length of the compass is too short for sharp orientation and for projecting lines of intersection; but if the accuracy of all the rest of the work is consistent with that obtained from the use of this style of alidade, there will be no appreciable errors when the map is reduced for publication. The writer has found, in fact, that in reducing a field-map on a scale of 500 feet to the inch down to a publication scale of 2,000 feet to the inch, considerable more

detail is had than can be used in certain places without generalizing and accentuating some lines. Such is to the credit of a large scale map in field work.

Some of the special features of the roller-board may be summed up as follows:

1. It permits of the field-use of a large connected map without folding.

2. It holds the map at a proper height and furnishes a flat even surface for the drawing and writing of notes.

3. Long intersections can be made as well as having all other advantages of the ordinary plane-table.

4. It enables the geologist to always have his complete data in the field for back reference and comparison.

5. When the field map is completed, it is connected and can very quickly be prepared for the draughtsman.

JAMES H. GARDNER.

MANGANESE IN SUPERFICIAL ALTERATION.

Sir: I am glad to have the opportunity to contribute to ECONOMIC GEOLOGY the following summary of an article which has appeared in the *Philippine Journal of Science.*

In applying the hypothesis advanced by Emmons in his article[1] "The Agency of Manganese in the Superficial Alteration and Secondary Enrichment of Gold-Deposits in the United States," to the gold deposits of the Philippines, I found that the majority of deposits were exceptions to the rule. These exceptions were practically all cases where the gangue contained large amounts of calcite. An examination of the examples given in the last section of the article mentioned above showed the majority of deposits which do not show impoverishment in the upper level nor enrichment near ground water level are calcite-bearing. This led to a series of experiments and investigations, resulting in a preliminary article called "Alteration and Enrichment in Calcite-Quartz-Manganese Gold-Deposits in the Philippines." The

[1] *Bulletin of American Institute of Mining Engineers,* November, 1910, No. 47, p. 767.

manuscript was handed in to the editor of the *Philippine Journal of Science* in October, 1912, and is probably now in transit from there in the mails.

The principal points brought out in this paper are given below.

The characteristics of Calcite-Quartz-Manganese veins due apparently to the presence of calcite are: 1. The mine-waters are neutral or alkaline at practically all horizons above ground-water level. 2. Owing to this fact no free chlorine can be formed. 3. Should nascent chlorine be formed it would readily attack the calcite, so that little or no chlorine would remain uncombined and free to attack the gold. 4. Should gold chloride be formed, some of the gold, at least, would be precipitated at approximately the same horizon by ferrous sulphate (produced from the oxidation of the iron pyrites) or by the calcite.

Laboratory experiments were made with concentrated reagents and all showed that no free chlorine would be formed in a vein as long as the oxidizing waters were neutral or alkaline, or only slightly acid, and that free chlorine is formed only when solutions are decidedly acid and iron is absent. When iron is present, ferric chloride is formed which acts as a solvent of gold in the presence of manganese dioxide.

Several samples of mine waters from various levels of deposits containing calcite were obtained and analyzed. No free chlorine was found; all were either neutral or slightly alkaline to litmus paper; and all contained large amounts of the bicarbonic acid radicle, sulphuric acid radicle, and calcium, and small amounts of iron and manganese.

Field examination of these ore deposits and careful sampling showed that the richest ore was at, or near, the surface and that the values decreased almost uniformly with depth. This would indicate that solution of gold by chlorine had probably not taken place. Furthermore where the values were highest, from 20 to 30 per cent. of the gold content could be recovered by amalgamation and placer deposits resulted from them.

These conditions are directly opposed to those where leaching by the solution of gold with free chlorine has taken place.

Enrichment in this type of vein is caused by (1) the leaching of the calcite, which causes a removal of a valueless element, leaving a smaller mass of richer ore, and (2) by mechanical concentration of fine gold along channels caused by fracturing and by the removal of the calcite by solution.

F. T. EDDINGFIELD.

THE FORMATION OF THE SECONDARY SILICATE ZONE IN CONTACT-METAMORPHIC ORE-DEPOSITS.

Sir: That recrystallization of the impurities originally present in a limestone plays some part in the formation of the secondary silicates of contact-metamorphic zones will hardly be denied even by those who believe that magmatic emanations have added their quota of silica, iron and alumina to aid in forming the new minerals. It has been admitted by Barrell for the Marysville deposits[1] and by Knopf for those on the Seward Peninsula,[2] even though in both cases it is shown that magmatic additions are also important, and the present writer some years ago maintained that careful study would probably show in most contact metamorphic ores two series of silicates—one due to recrystallization, and the other the result of magmatic additions.[3] I believe, however, that the latter process is the predominating one, and that the facts do not bear out the contention of Mr. Uglow that "the balance of the evidence seems to be quite in favor of the origin of the secondary silicate zones by the elimination of the excess of $CaCO_3$ and the recrystallization of the impurities into lime silicates."[4] According to his definition Mr. Uglow includes in "secondary silicates" all silicates of the contact zones not containing fluorine, boron, or other mineralizers, and that means for the districts cited practically all of the contact minerals, for tourmaline, fluorine, etc., are notably scarce or entirely lacking.

[1] U. S. Geol. Sur., Prof. Paper 57.
[2] U. S. Geol. Sur., Bull. 358.
[3] *Eng. and Min. Jour.*, September 10, 1910.
[4] ECON. GEOL., VIII., p. 233.

The chief point made by Mr. Uglow in the paper cited is that a comparison of the analyses of fresh and metamorphosed limestones shows little variation in the respective ratios of silica, iron and alumina. In support of this he plots the ratios on a straight line diagram, and calls attention to the slight departure of the lines plotted from the perpendicular. It should be noted, however, that the slope of these lines is dependent upon the relative scale used for the abscissas and ordinates, and that these have no fixed relationship to each other. Mr. Uglow might have placed the vertical lines representing 100, 200, etc., many times farther apart, or the horizontal lines representing SiO, Al_2O_3, etc., much nearer together, and in either case the slope of the plotted lines would have been much greater. Because there is no factor that can determine the relative vertical and horizontal scales of the diagram, the slope of the plotted lines merely shows that the changes in lime and magnesium ratios are greatest—which everyone admits, and which does not bear upon the problem.

If we study the *figures* plotted, we see that in many cases there is far from a "relative constancy" in the ratios discussed, for example, Iron Springs, SiO_2 15.5, Al_2O_3 20.9, Fe 12.0; Bisbee, SiO_2 8.8, $Al_2O_3 + Fe_2O_3$ 11.1, White Knob, SiO_2 21.5, $Al_2O_3 + Fe_2O_3$ 8.0, Morenci, SiO_2 2.9, $Al_2O_3 + Fe_2O_3$ 5.3. The fact that there is considerable variation between the ratios of these substances in the fresh and altered limestones is brought out in the following table, the analyses being taken from Mr. Uglow's paper, except in the case of Silverbell, which he does not consider. The numerical results are essentially the same as Mr. Uglow's, but this way of stating them makes the situation apparent at a glance.

Iron Springs:

	Unaltered limestone.	Metamorphosed limestone.
$\frac{SiO_2}{Al_2O_3}$	= 4.15	5.58
$\frac{Al_2O_3}{Fe}$	= 2.95	1.71

Hastings Co., Ont.:

$$\frac{SiO_2}{Al_2O_3} = 3.63 \qquad 2.73$$

$$\frac{Al_2O_3}{Fe} = 2.79 \qquad 2.93$$

Bisbee, Ariz.:

$$\frac{SiO_2}{Al_2O_3 + Fe_2O_3} = 10.5 \qquad 13.19$$

White Knob, Ida.:

$$\frac{SiO_2}{Al_2O_3 + Fe_2O_3} = 3.46 \qquad 1.28$$

Chinacello, Chile:

$$\frac{SiO_2}{Al_2O_3 + Fe_2O_3} = 6.49 \qquad 4.74$$

San Jose:

$$\frac{SiO_2}{Al_2O_3 + Fe_2O_3} = 7.18 \qquad 7.46$$

Silverbell, Ariz.:

$$\frac{SiO_2}{Al_2O_3 + Fe_2O_3} = .64 \qquad 1.18$$

Morenci:

$$\frac{SiO_2}{Al_2O_3 + Fe_2O_3} = 9.97 \qquad 1.35$$

The above figures show an approximate constancy only in the cases of San Jose, and Hastings County; in the others there is a variation of from 20 to 700 per cent.[1] In quoting the analyses Mr. Uglow states that they are not entirely reliable because they represent analyses of a single contact mineral, and not of average

[1] In actual fact the only reliable way to compare fresh and altered rocks is on the basis of some one constituent remaining constant as Leith and Harder for Iron Springs. The present method is used here because it is Mr. Uglow's, and this letter is concerned with his arguments.

samples of the contact zone. It must be remembered that contact zones are in many cases solid masses of garnet with very subordinate amounts of the other silicates and some calcite, and were such a thing as an average sample possible (which it often is not, in view of the bunchy irregular distribution of the minerals), it would probably not alter the ratios under discussion.

If the silicate zone represented a recrystallization of the residual part of the limestone, the proportion of alumina to silica and iron should be somewhat greater in the altered rock, for alumina is less readily removed. Yet at Iron Springs, a locality famous because here Leith and Harder first advanced the hypothesis of recrystallization after leaching, the reverse is the case, both iron and silica having increased relative to alumina.

In fact the point most strongly insisted upon by Professor Kemp in all of his studies on this subject is not that the garnet represents the actual additions from the magma, but that the garnet is largely an *iron* garnet, and that the preponderance of iron in the metamorphosed zone is too great to be explained on the basis of recrystallization of an ordinary limestone. In many of the western occurrences, garnet so far preponderates that there is no possibility of alumina being increased by other minerals that have not been included in the analysis. At Silverbell, for example, aluminous minerals are present in the contact zone only in microscopic accessories. Practically all of the alumina is present in the garnet, yet this mineral contains twice as much iron as alumina.[1] Surely it must have been an unusual limestone that after the leaching necessary to remove much of the CaCO would still contain such an excess of iron over alumina. Moreover the iron could not have been concentrated at the contact by leaching by meteoric waters as Professor Lawson's hypothesis would assume, for at Silverbell the limestone occurs as small blocks completely swamped in the intrusives. At the time of the formation of the garnet, meteoric water (except that small amount included in the sediments) could have reached the contact only by seeping

[1] C. A. Stewart, "Geology and Ore Deposits of Silverbell, Ariz.," A. I. M. E., *Bull.*, May, 1912.

through the heated igneous rocks or by working downward into regions of high temperature.

Of the cases discussed that in Hastings County seems on basis of the ratios to fit the recrystallization hypothesis, and this may well be because that locality is not connected with the Western Cretaceous intrusives so rich in magmatic waters. Professor Kemp's paper shows that at San Jose the garnet contains iron all out of proportion to the iron in residual clays.

The paragenesis of minerals in contact zones is not simply silicates first and ores second, but is more complex. Some years ago I plotted the order of formation of contact minerals from all descriptions available, and concluded that "there is a series of silicates formed first. After these come the ore-minerals, usually intergrown with a second series of silicates, and there is often a period of formation of contact minerals continuing after the ore-deposition."[1] This accords with the idea that a part of the contact silicates are formed by recrystallization, but that magmatic additions of silica, iron and alumina accompany if they do not precede the ores.

The lack of evidence of replacement as seen in some deposits is explained by Dr. Stutzer's theory of "pegmatite-like deposition"[2] which Mr. Uglow does not mention, and surely the quartz and calcite in juxtaposition are as puzzling under the recrystallization hypothesis as under that of magmatic emanations.

The statement that "alumina is unknown in magmatic emanations" is often boldly made, but still lacks proof. Our only direct evidence in regard to magmatic emanations (if we exclude the contact zones) comes from analyses of volcanic gases, and of course alumina is not found there because of reduced heat and pressure. On general probability, however, there is no reason why hot water coming from a magma under great pressure should not carry some alumina in solution. This is supported by the presence of alumina in the aquo-igneous pegmatites, and by the occasional presence of adularia in veins. Alumina would be less

[1] *Eng. and Min. Journ.*, September 10, 1910.
[2] *Zeitschrift für praktische Geologie*, XVII., pp. 145–155.

in amount in magmatic waters and would not be carried far from the intrusive.

It seems to the writer that the only way to deny the importance of magmatic additions in contact zones is to deny that there have ever been magmatic waters issuing from the intrusive. If one admits, as does Mr. Uglow, that waters do issue from the intrusive, he surely will be hard pressed for an explanation of their inability to carry in solution some of the elements contained in the rocks through which they have passed. That elements like potash, soda, etc., are less frequently found at the contacts is explained by their greater solubility permitting them to migrate into colder regions. The recent work of Spurr and Garrey has shown alteration of the intrusives themselves that can be accounted for only on the basis of magmatic waters carrying in solution much mineral matter. This alteration continues up to the contact. Why should it then not effect the more susceptible limestone?

The matter of volume changes has already been discussed by Professor Kemp, and need not be entered into here. The sum of this matter seems to be that in some instances the evidence in regard to volume changes is of no value because of the disturbances attendant upon intrusion, but that there are other cases in which structure of the original rock has been replaced *in situ* by contact minerals. In such instances leaching of the limestones and recrystallization of the residual products cannot apply even with the wildest stretch of the imagination.

When contact metamorphism follows impure beds it does not necessarily mean that no magmatic addition has taken place, but simply that there has first been a recrystallization forming a porous bed into which the magmatic solutions penetrate most easily, as has been suggested by Weed. The fact that selective metamorphism is sometimes in the purer beds indicates that recrystallization is not the only factor.

In summary then, while admitting that recrystallization plays a part in the formation of secondary silicates, we believe that in most cases it plays a minor rôle for the following reasons.

1. The ratios between the percentages of silica, alumina, and

iron in the fresh and unaltered rock *do not* remain the same, but show a variation ranging from 20 to several hundred per cent., and this supposed agreement between ratios is the chief affirmative argument advanced by the advocates of recrystallization.

2. Iron is frequently higher than alumina in the contact zones —a relationship not common in residual clays.

3. The order of crystallization, involving, as it does, two periods of silicate formation, is best explained on the ground of both processes being at work.

4. The preservation of original structures shows that in some instances, at least, leaching of the limestone could not have taken place.

5. Other supposed difficulties in the way of the theory of magmatic emanations are explained by some modifications of the theory advanced by Dr. Stutzer.

6. To deny that magmatic additions take place is to deny that magmatic waters issue from the intrusive, for if such waters do issue they must carry material in solution.

The occasion for the whole dispute on this subject seems to be the fact that both recrystallization and magmatic additions have taken place, and that observers are too prone to apply what they have seen in one district to other districts. It is not always possible to distinguish between the effects of recrystallization and "additive metasomatism" as Barrell has done at Marysville, but the evidence cited above does seem to show that in the western localities the second process has been of great importance. I am unwilling to believe that this evidence, collected by such observers as Kemp, Lindgren and Spurr, is rendered worthless by the "personal equation," and I cannot see how any personal equation could explain the enormous solid masses of *iron* garnet at Silverbell on the basis of recrystallization.

C. A. STEWART.

"ALGONKIAN" VS. "PRE-CAMBRIAN."

Sir: In the April–May number of ECONOMIC GEOLOGY over the signatures of eight New England geologists I note the following:

"*In the judgment of the undersigned* it is not as yet possible to divide the Pre-Cambrian by any universally applicable line of correlation and stratigraphic division. We deprecate the use of the term *Algonkian* since it does not definitely connote anything further than *Pre-Cambrian*."

As one of the unregenerate, not entirely convinced by italics and capital letters, I venture to ask that this committee be more explicit and state the facts upon which its views are based. Does the committee wish to apply to all districts the statement that Algonkian does not definitely connote anything farther than Pre-Cambrian? Does it maintain that there are no districts in which a dual classification of the Pre-Cambrian expresses essential facts of present knowledge? If there are such districts does the committee care very much what terms express it? Does the committee mean merely that there are some districts in which the term Algonkian has no definite significance? Have the members of the committee studied Pre-Cambrian areas and found new facts not heretofore known? There is no essential difference of opinion that the Algonkian may not have universal application, and in the present state of knowledge certainly cannot be universally applied. This being true, is not the committee fighting a windmill in deprecating universal application?

I have no wish to enter into a controversy in a matter of nomenclature. It makes little difference with what names we describe the facts, but as one who has worked more or less continuously in the Pre-Cambrian in various parts of North America I feel that the committee is either ignoring certain essential facts in some districts which must somehow be expressed by names or has been unfortunate in the phrasing of its statement. A considerable number of geologists, probably with knowledge of Pre-Cambrian conditions not less than that of the signers of the above declaration, have found it convenient and desirable to use the terms Archean and Algonkian. Certainly these men have thought that the terms connoted something definite and should have statements of fact to convince them of the error of their ways.

C. K. LEITH.

REVIEWS

De Re Metallica. By GEORGIUS AGRICOLA. Translated by HERBERT CLARK HOOVER and LOU HENRY HOOVER. The Mining Magazine, London, 1912.

With the subject matter of De Re Metallica the reviewer need not here concern himself. That renowned work links the Middle Ages with modern achievement in mining and metallurgy and marks the utmost bourne beyond which bibliographic research in those subjects becomes merely an antiquarian pastime. References to Agricola, the Latinized name of the learned and industrious Saxon physician Georg Bauer, are common in comprehensive works on the metals but the Latin in which that author wrote had to be eked out by so many technical terms unknown of course to the classic tongue and unfamiliar to later students of the literature of Rome, that his work has hitherto baffled attempts to translate it into English and consequently has been read by few in the countries where mining engineering has attained its greatest development.

Mr. and Mrs. Hoover, in undertaking what was evidently a labor of love, refused to be discouraged by the difficulties that had brought to nought earlier attempts to perform the same task. To complete so laborious a work in "night hours, week ends, and holidays" snatched from "active endeavor in many directions" and within the space of five years scarcely suggests the need for the apology offered by the translators for delayed publication. The result well illustrates the paradox that those who have most to do in this life are the ones who find time for additional achievement.

The book is far more than a translation. It is enriched throughout by copious notes which are exceptionally valuable as the fruit of the rare combination of authoritative knowledge of modern mining with bibliographic patience and skill of a high order. The translators also furnish an interesting introduction on Agricola's life, times and work, with two bibliographic appendixes and an appendix on weights and measures, and full indexes.

The volume, a large octavo of 640 pages, contains reproductions of all of the quaint woodcuts of the original, is beautifully printed on fine paper with antique finish, and is strongly bound in vellum. The proof was evidently read with unusual care and there are very few

typographical errors. The only one noted which is at all likely to mislead is the statement on page 112 that "brass was made by cementing zinc ore with copper." Evidently for *cementing* we should read *smelting*.

F. L. RANSOME.

The Geology of Soils and Substrata. By HORACE B. WOODWARD, F.R.S., F.G.S. Longmans, Green, and Co., London, 1912. 8vo., pp. xvi + 366, with 4 Pls. 44 figs.

Whether or not there is good reason for it, it appears that there is commonly not a very close coördination between geological and soil surveys. The reports of both state that soils are a product of rock decay and show different characters according to the rocks from which they were derived, but the members of one service are generally not well informed on the progress and results of the other, and there seems to be much fear of trespassing.

Occasionally a book is published which brings to mind the natural close relation between the two lines of work and a noteworthy contribution of this sort bears the title and authorship indicated above. The object of the author of this book is "to provide such information relating to the land-surface as will be useful to students and teachers of agriculture, to those occupied in the management of estates and farms, or in sanitary and engineering works, wherein it is important to consider the geological nature of different sites for residences and other purposes." Thus, not only are soils discussed but municipal water supply, sewage, the locating of houses and cemeteries, and the value of geology to engineers, architects and land agents generally.

In the first three chapters the elements of geology and the relation of geology to agriculture and scenery are briefly reviewed In the next chapter there is discussed the very important subject of geologic and soil maps including some interesting historical notes, such as that a soil map of England was seriously considered in the seventeenth century and that in 1819 William Smith commenced to issue a new "Geological Atlas of England and Wales on which are delineated, by colours, the courses and width of the strata which occasion the varieties of soil." One could wish, however, for a more extended discussion of the natural relationship in the making and use of the two classes of maps which are commonly regarded as such distinct products. Several pages are given to the rudiments of geologic mapping, most of the remarks here, as elsewhere throughout the book, applying primarily to England. One of the important thoughts presented is that the more detailed the geologic map the more closely does it approach to a soil map. A good

inch-to-the-mile geologic map, although useful in some degree to the farmer, is only a general sketch map, but the 6-inch geologic maps now being prepared for England will need little modification to serve as soil maps.

The fifth and sixth chapters treat rocks and rock weathering in an elementary way, brief descriptions of the principal kinds of rock being given; the seventh is made up of notes on various kinds of soil; the eighth takes up the physical conditions affecting soils and the ninth chemical and mechanical analyses including about a page on bacteria. The tenth chapter is entitled "Fertility and Barrenness of Lands," but does not enter very deeply into the reasons for these characters. The eleventh chapter on "Drainage and Irrigation" closes with a description of water meadows (land both irrigated and drained) which will be new to many readers. The twelfth chapter treats of fertilizers and the thirteenth the effect of forests on soil and the relation between soils and the growth of various kinds of forests. The fourteenth chapter takes up the soil requirements for orchards, market gardens, and vineyards and the fifteenth geological considerations concerning estates and mineral rights, various mineral products and their geological horizons being reviewed. The sixteenth is on locating houses and cemeteries and the remaining nine chapters treat the geological formations of Great Britain beginning with the most recent and describing their economic value and soil derivatives.

On the whole the scope of the book is broad and the presentation orderly. The subject matter consists of more or less elementary facts collected from many sources, and presented somewhat after the manner of an encyclopedia. The statements are generally reliable but some, particularly those referring to areas outside of Europe, are open to question. For example loess and adobe are made synonymous ("*Adobe*, a term applied to the loess in America," p. 42). The book is supplied with a good index in which many unfamiliar terms are listed and will be found to be interesting reading and a valuable reference volume.

E. W. SHAW.

SCIENTIFIC NOTES AND NEWS[1]

THE ONE HUNDRED FIFTH meeting of the American Institute of Mining Engineers will be held at Butte, Montana, from August 18 to 21. This is the first meeting which has been held since the recent organization of the Committee on Mining Geology, appointed by President Charles F. Rand. It is expected that a very large accession of valuable and interesting papers on geological subjects will be received and published by the institute as a result of the new policy in organizing this committee. The membership of the committee is as follows: Waldemar Lindgren, chairman, John W. Finch, vice chairman, R. A. F. Penrose, Jr., vice chairman, Louis C. Graton, secretary, James F. Kemp, Joseph Hyde Pratt, C. K. Leith, Ezequiel Ordonez, Reno H. Sales, Henry Landes, H. A. Buehler, Heinrich Reis, Josiah E. Spurr, Marius R. Campbell, Ralph Arnold, H. Foster Bain, Horace V. Winchell, Frederick L. Ransome, John M. Boutwell, H. L. Smyth, Wm. G. Sharp, Alfred Church Lane, William H. Emmons, R. V. Norris.

SHORTLY AFTER THE DEATH of the late Samuel Franklin Emmons, a group of his friends gathered together with the intention of establishing a memorial which would serve in some measure to commemorate the valued service which he has rendered to the science of economic geology. Mr. Benjamin B. Lawrence, of 60 Wall Street, New York, was appointed secretary and treasurer and the following members were selected as a committee: Geo. Otis Smith, H. L. Smyth, James Douglas, J. A. Holmes, J. D. Irving, James F. Kemp, F. W. Bradley, J. Parke Channing, Seeley W. Mudd, David W. Brunton, H. Foster Bain.

Through the efforts of Mr. Benjamin B. Lawrence, and notably of Mr. Arthur B. Emmons, a beginning of approximately

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.

$15,000 was raised and after consultation with the committee it was decided to have a traveling fellowship established at Columbia University. It is hoped that the fund may be increased by larger subscriptions and that those who are able to subscribe will do so, sending the money to Mr. Lawrence.

A Permanent Committee of Award has been appointed consisting of Mr. Waldemar Lindgren, Mr. J. F. Kemp and Mr. J. D. Irving. The recommendation of the incumbent will be made by the Committee of Award and also directions given as to the manner in which the money shall be expended. The incumbent of the fellowship will study at any of the eastern universities in accordance with the directions of the Committee of Award. The object of the fellowship is to promote research in the problems of economic geology. It is believed that this fellowship will do much to stimulate interest among younger men and will be a most admirable commemoration of the services rendered by Mr. Emmons.

CHARLES T. KIRK (Ph.D., Wisconsin, 1911) has been appointed professor of geology in the University of New Mexico. Since 1909 the state of New Mexico has maintained a Natural Resources Survey, in which the professor of geology in the University is state geologist. Mr. Kirk will begin reconnaissance work on this survey during the present summer, with headquarters at the State University, Albuquerque, New Mexico.

L. G. HUNTLEY, of the Associated Geological Engineers, is at present engaged in a study of the Pelican Portage gas field and other localities in central Alberta for the City of Edmonton.

MR. LLOYD B. SMYTH, professor of geology in the Carnegie Institute of Technology of Pittsburgh, Pa., has resigned to enter the employ of the Associated Geological Engineers in the examination of oil and gas properties.

J. D. IRVING will be occupied during the months of August and September in the prosecution of work for the United States Geological Survey on the Leadville District, Colorado. Readers of ECONOMIC GEOLOGY are requested to address correspondence to Edgartown, Mass., during August and September.

A NUMBER of the larger copper mining companies of the United States have recently equipped a geological commission for the investigation of the problems of secondary sulphide enrichment of copper. The work has been put under the charge of Professor L. C. Graton, of Harvard University. The investigating staff of the commission is made up as follows: Geologists, L. C. Graton, Augustus Locke, A. M. Bateman, Joseph Murdoch, E. H. Perry; chemists, E. T. Allen, J. L. Grenshaw, E. G. Zies, Eugen Posnjak; petrologist, H. E. Merwin. The object of the work is to visit all of the prominent copper mines possible in order to investigate the problem from a scientific standpoint and to render conclusions so obtained practically valuable to the various companies which have promoted the enterprise. It is believed that much will be done in the interests of the science of economic geology by this progressive step on the part of the mining companies. Geologists will look forward with interest to the completion of the work two years hence.

A. M. BATEMAN, who completed the course for the degree of doctor of philosophy in Yale University this June, has been appointed a member of the geological corps of the recently equipped commission for the investigation of the problems of secondary sulphide enrichment of copper. Mr. Bateman was formerly a member of the Canadian Geological Survey.

FRANCIS CHURCH LINCOLN has resigned his position as professor of mining engineering at the University of Illinois and gone to South America as resident engineer for the Bolivian Development and Exploitation Company, with headquarters at La Paz, Bolivia.

A CIVIL SERVICE EXAMINATION will be held on August 6 and 7 of the present year for the position of editorial clerk, the salary ranging from $1,500 to $1,800 a year. The examination is designed to fill a vacancy now existing in the Geological Survey. It is to be hoped that as many applicants may be secured as possible as the position is one of considerable importance to the work of the Geological Survey. The circular recently issued by the Civil Service Commission states that the examination will require two

days and that the following subjects will be covered with the respective weights given opposite to them.

Subjects.	Weights.
1. English (correction of expression)	40
2. French and German footnotes (translation into English)	10
3. Proof reading and indexing	30
4. Elementary geology and geologic nomenclature	20
Total	100

Persons whose applications are approved will be furnished with copies of the following publications: "Publications of the United States Geological Survey"; "Suggestions to Authors of Papers Submitted for Publication by the United States Geological Survey." Examinations will be held at the request of applicants in the various states and territories of the United States. Blanks with further information will be furnished by the Geological Survey on request.

THE FOLLOWING INFORMATION concerning special rates made for the International Geological Congress has been furnished by the New York Central Lines:

The summer excursion fare, New York to Toronto and return via New York Central (all rail) is $22.15 and via Buffalo, Niagara on the lake and steamer, $20.40. The Pullman fare, New York to Buffalo or Niagara Falls, is $2.00 for lower berth; $1.60 for upper berth; and $7.00 for drawing room; and from New York through to Toronto, the cost of lower berth is $2.50; upper berth $2.00 and drawing room $9.00 Parlor car seat, New York to Buffalo or Niagara Falls, costs $2.00 and to Toronto $2.50. In connection with the trip to Toronto, there are a large number of circular tours that may be taken. Information concerning these will be furnished by the railroad upon application to W. V. Lifsey, General Eastern Passenger Agent, 1216 Broadway, New York.